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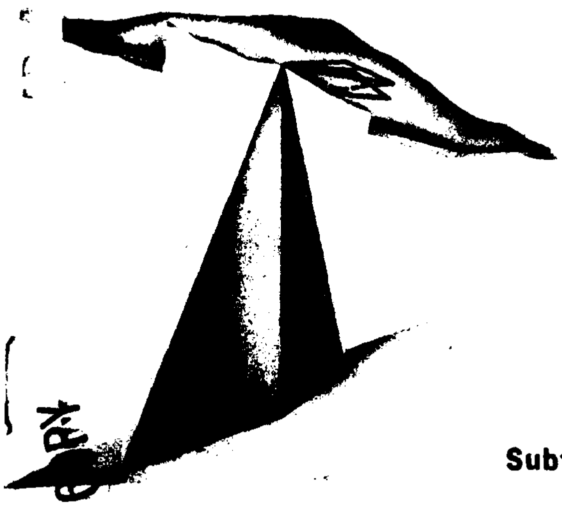
WKB MODE SUMMING PROGRAM FOR DIPOLE ANTENNAS OF ARBITRARY ORIENTATION AND ELEVATION FOR VLF/LF PROPAGATION

Calculation of vlf/lf field strengths in the earth-ionosphere waveguide



JA Ferguson
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1 October 1981

Interim Report for Period October 1980 - May 1981

Prepared for
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The computer program described in this report is a modified version of that described in NELC Interim Report 713, NTIS, AD728414. Changes consist of an increase in the number of waveguide slabs from 25 to essentially an unlimited number, more convenient formatting of the input data, especially in the reduction from three to two cards per waveguide mode, an increase in the number of allowable modes from 15 to 30, and the addition of two new output options. This program is referred to as WKBFLDS or FLD4.

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OBJECTIVE

Develop a computer program for calculating vlf/lf field strengths in the earth-ionosphere waveguide whose characteristics may vary along the direction of propagation.

RESULTS

The computer program described in this report is a modified version of that described in NELC Interim Report 713, WKB Mode Summing Program for VLF/LF Antennas of Arbitrary Length, Shape, and Elevation. Changes consist of an increase in the number of waveguide slabs from 25 to essentially an unlimited number, more convenient formatting of the input data, especially in the reduction from three to two cards per waveguide mode, an increase in the number of allowable modes from 15 to 30, and the addition of two new output options. This program is referred to as WKBFLDS or FLD4.

RECOMMENDATIONS

Use this program in instances where the characteristics of the earth or ionosphere vary slowly along the propagation path.

CONTENTS

INTRODUCTION

Electromagnetic radiation in the lower frequency bands emitted in the region between the finitely conducting earth and the weakly ionized plasma of the lower ionosphere is guided by these boundaries and propagated to great distances around the earth. The waveguide model analyzes this propagation using a mode series (ref 1-4). The propagation parameters of interest (phase velocity, attenuation rate, excitation factor) can be evaluated for each mode. The total field at any point along the guide is then the vector sum of the contributions from each mode. The waveguide model has been employed in a series of computer programs (ref 5-7) useful from elf to lf.

In many instances, the earth-ionosphere waveguide can be considered to have constant propagation properties along the transmission path. The mode sum calculations made for these cases are referred to as horizontally homogeneous. However, for propagation to great distances it is unrealistic to assume the waveguide parameters will remain constant along the whole length of the path. For example, the direction and strength of the earth's magnetic field will vary along the path, causing changes in the mode parameters due to the anistropy of the ionosphere. Discontinuities can occur in the lower wall of the waveguide due to the presence of ground conductivity changes. The ionospheric conductivity varies according to the time of day, season, and the presence of the sunrise or sunset line along the propagation path. Anomalous ionization from a nuclear detonation may also produce important changes in mode parameters along the propagation path. If changes in the waveguide parameters are small within a few radio wavelengths, then the modes can be tracked through the region of change.

The computer program described in this report was developed for calculating vlf/lf field strengths in the earth-ionosphere waveguide. Allowance is made for horizontal inhomogeneity in the direction of propagation. The program is based upon a slab model and assumes the waveguide is homogeneous transverse to the great circle path between a transmitter and a receiver. For purposes of identification it is called FLD4 or WKBFLDS.

In the FLD4/WKBFLDS program, field strength calculations can be generated for all electric field components, at any receiver height within the waveguide, generated by electric dipole exciters of arbitrary orientation located

at any height within the guide. Transmitter and receiver heights must be within the free-space portion of the waveguide.

In describing the WKBFLDS computer program, familiarity is assumed with references 5 and 7 which describe FORTRAN programs for obtaining waveguide mode constants within the earth-ionosphere waveguide. Relevant outputs from these programs are the mode eigenangles and four independent quantities from which the excitation factors may be determined. Principal outputs of the WKBFLDS program are listings of the mode sum parameters and the corresponding plots. The field strengths are given in dB above 1 μV/m and the phase is given relative to free space propagation.

The Summary of the Equations section summarizes the relevant formulae. A description of the program input, output, and operating procedures is given in the Program Execution section. The appendix contains a FORTRAN listing of the computer program.

SUMMARY OF THE EQUATIONS

BACKGROUND

In the propagation of vlf and lf terrestrial radio waves to great distances, the waves are confined within the space between the earth and the ionosphere. This space acts as a waveguide.

The waveguide mode method described in references 6 and 7 obtains the full-wave solution for a waveguide that is characterized by arbitrary electron and ion density distributions and collision frequencies with height and a lower boundary which is a smooth homogeneous earth with an adjustable surface conductivity and dielectric constant. The model allows for earth curvature, ionospheric inhomogeneity, and anisotropy.

The propagation geometry is shown in figure 1. The vertical coordinate is z, the direction of propagation is x, and y is normal to the plane of propagation. Thus, the fields exhibit no y dependence and have a dependence on x of the form $\exp(-ikS_m x)$. All field quantities are assumed to have an $\exp(i\omega t)$ dependence where ω is the angular frequency. The dipole source for the fields is denoted in figure 1 by $\vec{M}$. The dipole is oriented at an inclination angle γ

measured from the vertical, and azimuthal angle θ measured from the x-axis. For a horizontal dipole $\gamma = 90°$, and $\theta = 0°$ represents end-fire launching.

The energy within the waveguide is considered to be partitioned among a series of modes called the eigenangles (or "modes") and designated by the complex angle, Θ, obtained by solving the determinantal equation:

$$F(\Theta) = |\underset{\sim}{R}(\Theta)\ \underset{\sim}{\bar{R}}(\Theta) - 1| = 0 \qquad (1)$$

where

$$\underset{\sim}{R}\ (\Theta) = \begin{pmatrix} {}_{\parallel}R_{\parallel}(\Theta) & {}_{\perp}R_{\parallel}(\Theta) \\ {}_{\parallel}R_{\perp}(\Theta) & {}_{\perp}R_{\perp}(\Theta) \end{pmatrix} \qquad (2)$$

and

$$\underset{\sim}{\bar{R}}(\Theta) = \begin{pmatrix} {}_{\parallel}\bar{R}_{\parallel}(\Theta) & 0 \\ 0 & {}_{\perp}\bar{R}_{\perp}(\Theta) \end{pmatrix} \qquad (3)$$

are the complex ionospheric reflection coefficient matrices looking up into the ionosphere and down towards the ground, respectively, from a height "d".

Once equation 1 is solved for as many modes, Θ_m, as needed, the mode parameters, phase velocity, attenuation rate, and excitation factors can be computed. Let S_m be the sine of the eigenangle Θ_m and let the individual components be S_r and S_i so that $S_m = S_r + i\ S_i$. The phase velocity is given by

$$v = \frac{c}{S_r} \qquad (4)$$

where c is the vacuum speed of light.

The attenuation rate is given by

$$\alpha = -8.6859k\ S_i \qquad \text{(in dB/unit distance)} \qquad (5)$$

where k is the free-space wave number.

The excitation factor formulae, as given in reference 1, are summarized in table 1. The headings apply to the electric field components (E_z, E_y, E_x) excited by a vertical dipole (z), a horizontal dipole broadside (y), and a horizontal dipole end-on (x).

Field Component / Exciter	z	y	x
z	$\frac{S^{5/2}\ (1+{}_{\parallel}\bar{R}_{\parallel})^2(1-{}_{\perp}\bar{R}_{\perp\perp}R_{\perp})}{F'(\Theta_m)\ \ {}_{\parallel}\bar{R}_{\parallel}\ D_{11}}$	$-\frac{S^{3/2}\ {}_{\parallel}R_{\perp}(1+{}_{\parallel}R_{\parallel})(1+{}_{\perp}R_{\perp})}{F'(\Theta_m)\ \ D_{12}}$	$\frac{S^{3/2}\ (1+{}_{\parallel}\bar{R}_{\parallel})^2(1-{}_{\perp}\bar{R}_{\perp\perp}R_{\perp})}{F'(\Theta_m)\ \ {}_{\parallel}\bar{R}_{\parallel}\ D_{11}}$
y	$-\frac{S^{3/2}\ {}_{\perp}R_{\parallel}(1+{}_{\perp}\bar{R}_{\perp})(1+{}_{\parallel}\bar{R}_{\parallel})}{F'(\Theta_m)\ \ D_{12}}$	$\frac{S^{1/2}\ (1+{}_{\perp}\bar{R}_{\perp})^2(1-{}_{\parallel}\bar{R}_{\parallel\parallel}R_{\parallel})}{F'(\Theta_m)\ \ {}_{\perp}\bar{R}_{\perp}\ D_{22}}$	$-\frac{S^{1/2}\ {}_{\perp}R_{\parallel}(1+{}_{\perp}\bar{R}_{\perp})(1+{}_{\parallel}\bar{R}_{\parallel})}{F'(\Theta_m)\ \ D_{12}}$
x	$-\frac{S^{3/2}\ (1+{}_{\parallel}\bar{R}_{\parallel})^2(1-{}_{\perp}\bar{R}_{\perp\perp}R_{\perp})}{F'(\Theta_m)\ \ {}_{\parallel}\bar{R}_{\parallel}\ D_{11}}$	$\frac{S^{1/2}\ {}_{\parallel}R_{\perp}(1+{}_{\parallel}\bar{R}_{\parallel})(1+{}_{\perp}\bar{R}_{\perp})}{F'(\Theta_m)\ \ D_{12}}$	$-\frac{S^{1/2}\ (1+{}_{\parallel}\bar{R}_{\parallel})^2(1-{}_{\perp}\bar{R}_{\perp\perp}R_{\perp})}{F'(\Theta_m)\ \ {}_{\parallel}\bar{R}_{\parallel}\ D_{11}}$

Table 1. Excitation factors

In table 1 the following terms are used:

$$F'(\Theta_m) = \left.\frac{\partial F}{\partial \Theta}\right|_{\Theta=\Theta_m} \tag{6}$$

$$F_1 = -\left\{H_2(q_o) - i\,\frac{n_o^2}{n_g^2}\left(\frac{ak}{2}\right)^{1/3}(n_g^2 - S^2)^{1/2}\, h_2(q_o)\right\} \tag{7}$$

$$F_2 = H_1(q_o) - i\,\frac{n_o^2}{n_g^2}\left(\frac{ak}{2}\right)^{1/3}(n_g{}^2 - S^2)^{1/2}\, h_1(q_o) \tag{8}$$

$$F_3 = -\left\{h_2'(q_o) - i\left(\frac{ak}{2}\right)^{1/3}(n_g^2 - S^2)^{1/2}\, h_2(q_o)\right\} \tag{9}$$

$$F_4 = h_1'(q_o) - i\left(\frac{ak}{2}\right)^{1/3}(n_g^2 - S^2)^{1/2}\ h_1(q_o) \tag{10}$$

$$q_z = \left(\frac{2}{ak}\right)^{-2/3}\left(1 + \frac{2}{a}\,z - S\right)^2 \tag{11}$$

$$H_j(q) = h_j'(q) + \frac{1}{2}\left(\frac{2}{ak}\right)^{2/3} h_j(q)\ ;\ j = 1,2 \tag{12}$$

$$n_z^2 = 1 + \frac{2}{a}z \tag{13}$$

$$n_g^2 = \frac{\quad}{\varepsilon_o} - i\,\frac{\quad}{\quad_o} \tag{14}$$

$$D_{11} = \left\{F_1 h_1(q_d) + F_2 h_2(q_d)\right\}^2 \tag{15}$$

$$D_{12} = \left\{F_1 h_1(q_d) + F_2 h_2(q_d)\right\}\left\{F_3 h_1(q_d) + F_4 h_2(q_d)\right\} \tag{16}$$

$$D_{22} = \left\{F_3 h_1(q_d) + F_4 h_2(q_d)\right\}^2 \tag{17}$$

where $\varepsilon/\varepsilon_o$ = dielectric constant of the ground and σ = the ground conductivity.

The subscripts on q and n represent the value of z at which these quantities are evaluated. The functions h_1 and h_2 are modified Hankel functions of order 1/3 as defined in reference 8. The primes on these quantities denote derivatives with respect to the argument.

The modal excitation factor and height gain functions are needed in computing electric field strengths. The excitation factors of table 1 must be supplemented with the height gain functions which are given in reference 1 as:

$$f_1(z) = \exp\left(\frac{z}{a}\right)\left\{F_1 h_1(q) + F_2 h_2(q)\right\} \tag{18}$$

$$f_2(z) = \{F_3 h_1(q) + F_4 h_2(q)\}/\{F_3 h_1(q_o) + F_4 h_2(q_o)\} \tag{19}$$

$$f_3(z) = \frac{1}{ik}\frac{df_1}{dz} \tag{20}$$

where f_1 is the height gain for the vertical electric field E_z, f_2 is the height gain for the horizontal electric field component E_y, and f_3 is the height gain for the horizontal electric field component E_x.

The basic mode sum equation is given by

$$E = \frac{\eta}{4\pi}\left(\frac{2\pi p}{10k}\right)^{1/2}\frac{k}{2}\frac{\Sigma E_m}{[a\ \sin(x/a)]^{1/2}} \tag{21}$$

where E = total electric field in volts/metre

E_m = complex amplitude of each mode

p = power radiated

η = free-space impedance

If the waveguide is homogeneous in the direction of propagation, then E_m is given by

$$E_m = \Lambda_m \exp\{-ik\ S_m x\} \tag{22}$$

where Λ_m is the complex amplitude of the mth mode to be described later. If the parameters Λ_m and S_m are slowly varying functions of distance, then the so-called WKB form of E_m is given by references 1 and 9 as

$$E_m = \Lambda_m(x) \exp\{-ik \int_o^x S_m(\rho)\ d\rho\} \tag{23}$$

where

$$\Lambda_m = \Big\{ [\lambda^m_{zr}(0)\ \lambda^m_{zr}(x)]^{1/2}\ g_z(z_t)\ \cos\gamma$$

$$+\ [\lambda^m_{yr}(0)\ \lambda^m_{yr}(x)]^{1/2}\ g_y(z_t)\ \sin\gamma\ \sin\theta$$

$$+\ [\lambda^m_{xr}(0)\ \lambda^m_{xr}\ (x)]^{1/2}\ g_x(z_t)\ \sin\gamma\ \cos\theta \Big\}\ g_r(z_r) \qquad (24)$$

and r denotes the orientation of the received electric field component. If equation 24 is used, then equation 26 reduces to

$$\Lambda_m = \Big\{ \lambda^m_{zr}\ g_z(z_t)\ \cos\gamma$$

$$+\ \lambda^m_{yr}\ g_y(z_t)\ \sin\gamma\ \sin\theta$$

$$+\ \lambda^m_{xr}\ g_x(z_t)\ \sin\gamma\ \cos\theta \Big\}\ g_r(z_r) \qquad (25)$$

WKB IMPLEMENTATION

The procedure implemented in the WKBFLDS computer program is to segment the earth-ionosphere waveguide into M cascaded uniform waveguides as shown in figure 2. These segments (or slabs) are numbered from left to right. Slab 1 contains the transmitter. The distance from the transmitter to the beginning of each slab is denoted by ρ_k. The waveguide parameters associated with each slab are determined by the user based on consideration of the variations of the path conditions (geomagnetic field, ground conductivity, and the ionospheric profiles of electron density, ion density, and collision frequency).

The mode generating programs (ref 6 or 7) are run to obtain as many modes as desired in each slab. The WKB model requires an equal number of modes in each slab and the modes must be traced from one slab to the next in order to preserve mode numbers. At each slab boundary energy is transferred from a given mode into the corresponding mode in the next slab. The values of Λ_m and S_m at the beginning of each segment are defined to be those obtained from the full-wave programs. The values of each quantity within each segment are obtained by linear interpolation between the values at the segment bound-

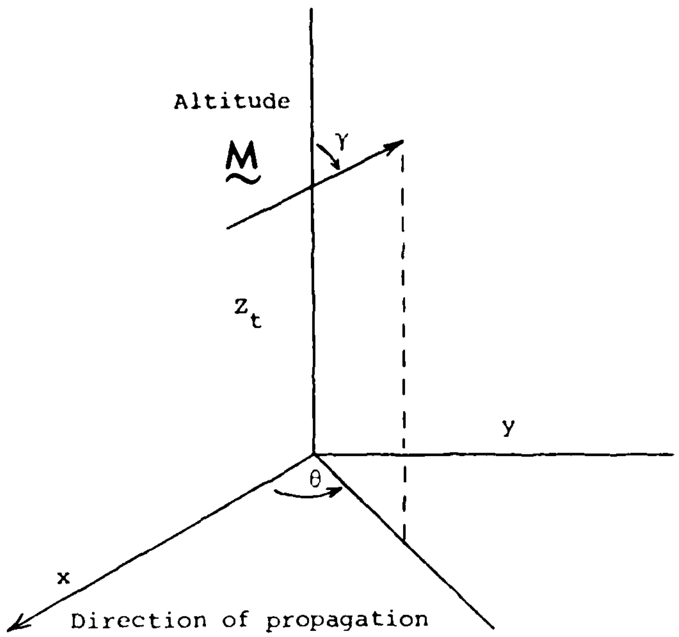


Figure 1. Dipole orientation within the waveguide

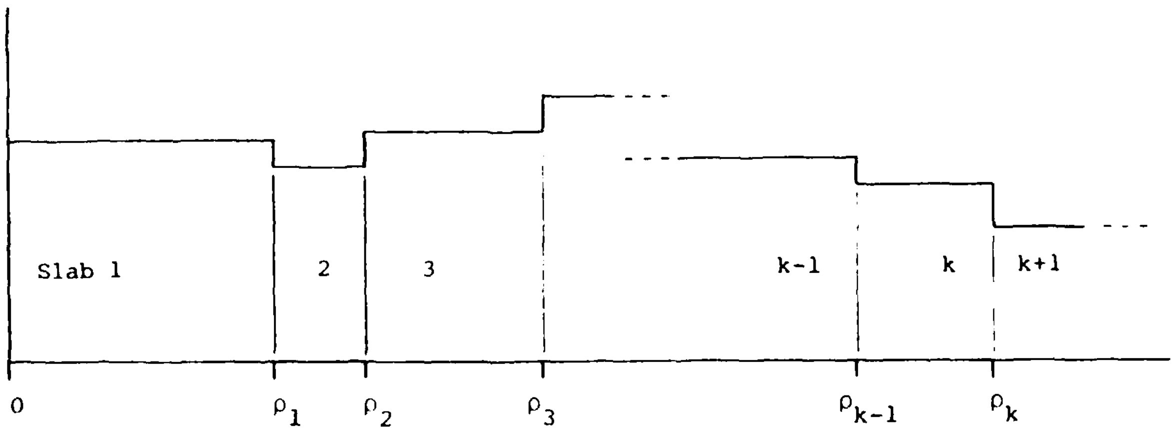


Figure 2. Diagram illustrating propagation path segmentation

aries. Care is taken to insure continuity of the phase of Λ_m and S_m from the transmitter to the receiver.

PROGRAM EXECUTION

OPTIONS

The program has three output options. For compatibility with other programs these options are numbered 1, 2, and 4. Option 1 produces fields as functions of distance parametric in transmitter altitude and orientation for a fixed receiver altitude and orientation. The program generates 501 points between the transmitter (distance = 0) and the end of the path (distance = DMAX, described below). The calculated fields and appropriate constants may be written to logical file 2 for processing by other programs. The calculated amplitude and relative phase may be printed and/or plotted. The vertical and horizontal (distance) dimensions and scales of the plots may be arbitrarily specified. Each set of distance calculations can be made for up to 20 transmitter orientations.

Option 2 produces fields as functions of a transmitter's position in an orbit for a fixed transmitter altitude and antenna inclination and for a fixed receiver altitude and orientation. The program generates 73 points between $\theta = 0°$ and $\theta = 360°$. Up to three different orbit configurations may be obtained: a dipole rotating in a counterclockwise direction, and clockwise and counterclockwise orbiting at a specified radius. Clockwise is determined by looking down the z-axis towards the x-y plane. Each set of orbit calculations is made at as many as 20 different distances from the transmitter. The calculated amplitude and relative phase may be printed. The results are always plotted using a fixed vertical size and scale and a user specified horizontal size.

Option 4 produces fields as functions of distance for fixed values of the transmitter and receiver altitudes and orientations. The data sets are varied so as to produce comparison plots. The printed and plotted outputs are all specified as for option 1. The procedure for storing the calculated fields on an external device is also provided as for option 1.

CONTROL CARDS

The flow of program execution is controlled by a set of cards which define the type of data being input and allow standard defaults to apply. All 80 columns of these control cards are read and printed. However, only the first four columns are examined by the program. Thus the input card and the printout can contain additional comments. For example, "NAMELIST DATA FOR AN ELEVATED TRANSMITTER" can be used in place of the minimum requirement of "NAME". The control cards are described below and a sample set is shown in figure 3.

NAME	Signals that NAMELIST data follow. The NAMELIST name is DATUM. The NAMELIST variables are described below.
IOPT	Option number - DEFAULT = 1
ICOMP	Index of received electric field component = 1 gives the vertical field (z) - DEFAULT = 2 gives the horizontal transverse field (y) = 3 gives the horizontal longitudinal field (x)
TALT	Transmitter altitude in km (ie, z_t) - DEFAULT = 0.0
RALT	Receiver altitude in km (ie, z_r) - DEFAULT = 0.0
INCL	Transmitting antenna inclination in degrees (ie, γ). This is an array of 20 elements - DEFAULT = 0.0
THETA	Transmitting antenna azimuth in degrees (ie, θ). This is an array of 20 elements - DEFAULT = 0.0
NRA	Number of pairs of INCL and THETA to be used. This applies only to option 1 - DEFAULT = 1
DIST	Distance between an orbiting transmitter and a receiver in Mm. This is an array of 20 elements - DEFAULT = 1.0
NRD	Number of values of DIST to be used. This applies only to option 2 - DEFAULT = 1
NRDATA	Number of input data sets to process for option 4 - DEFAULT = 1
RADIUS	Radius of the orbit in Mm used in option 2 - DEFAULT = 0.0
POWER	Total radiated power in kW - DEFAULT = 1.0

NPRINT	Printout control flag = 0 generates a minimum of print = 1 generates full print (described in example data section) - DEFAULT
NAPLOT	Amplitude plot flag = 0 deletes plot = 1 generates plot - DEFAULT = 0 deletes plot - DEFAULT = 1 generates plot
NPDIFF	Phase difference plot flag = 0 deletes plot - DEFAULT = 1 generates plot
NRCURV	Number of curves to be plotted per graph for option 1 and 4 - DEFAULT = 4
SIZEX	Length of the horizontal plot axis for current option in inches (for all options) - DEFAULT = 10.0
SIZEY	Length of the vertical axis for current option in inches (for options 1 and 4 only) - DEFAULT = 9.0
SIZEX1 SIZEY1	Length of axis for option 1 and 4 only - DEFAULT = 10.0, 8.0
SIZEX2 SIZEY2	Lengths of axes for option 2 only - DEFAULT = 1.0, 4.0 (note that SIZEY2 is included for completeness only, the value cannot be changed)
AMPMAX	Maximum value of amplitude to be plotted in dB above 1 μV/m for options 1 and 4 - DEFAULT = 70.0
AMPMIN	Minimum value of amplitude to be plotted - DEFAULT = -10.0
AMPINC	Tic mark intervals for amplitude axis in dB - DEFAULT = 10.0
PHSMAX	Maximum positive phase excursion to be plotted in degrees for options 1 and 4 - DEFAULT = 360.0
PHSMIN	Maximum negative phase excursion to be plotted - DEFAULT = -360.0
PHSINC	Tic mark intervals for phase axis in degrees - DEFAULT = 90.0
DMAX	Maximum distance of plot axis in Mm for options 1 and 4 - DEFAULT = 10.0
DMIN	Minimum distance in Mm - DEFAULT = 0.0
XINC	Tic mark intervals for distance axis in Mm - DEFAULT = 1.0

TOTAPE Integer flag for writing calculated fields to logical unit 2

= 0 deletes output - DEFAULT

= 1 generates output

TLONG Transmitter longitude (written to logical unit 2 when TOTAPE = 1) - DEFAULT = 0.0

TLAT Transmitter latitude (written to logical unit 2 when TOTAPE = 1) - DEFAULT = 0.0

RBEAR Geographic bearing from transmitter to receiver (written to unit 2 when TOTAPE = 1) - DEFAULT = 0.0

After reading the NAMELIST the program reads the next control card.

<u>DATA</u> Signals that the propagation path data follow. The format of these data is that which is produced by reference 7. The first card contains the data set identification. This card is used to supply a literal path description such as "HAWAII TO WAKE". This is followed by sets of mode constants, one for each path segment. The first card for each segment contains the starting distance (ρ), frequency (f), magnetic azimuth, codip and intensity, ground conductivity (σ), dielectric constant (ϵ/ϵ_o), and the nominal height of the free-space portion of the waveguide (h). Of these parameters, ρ, f, σ, and ϵ/ϵ_o must appear. The magnetic parameters and h are included for reference. This card is followed by the mode constants, one pair for each mode, containing the following information:

1	θ	T_1	T_2
2	θ	T_3	T_4

where 1 and 2 are sequencing indices, θ is the complex eigenangle at the ground, and Ts are complex constants described below.

$$T_1 = \frac{S^{1/2}(1 + {}_{\parallel}\bar{R}_{\parallel})^2(1 - {}_{\perp}R_{\perp}\,{}_{\perp}\bar{R}_{\perp})}{F'(O_j)\,{}_{\parallel}\bar{R}_{\parallel}\,D_{\parallel}} \qquad (26)$$

$$T_2 = \frac{S^{1/2}(1 + {}_{\perp}\bar{R}_{\perp})^2(1 - {}_{\parallel}R_{\parallel}\ {}_{\parallel}\bar{R}_{\parallel})}{F'(\Theta_j)\ {}_{\perp}\bar{R}_{\perp}\ D_{22}} \tag{27}$$

$$T_3 = \frac{S^{1/2}(1 + {}_{\parallel}\bar{R}_{\parallel})(1 + {}_{\perp}\bar{R}_{\perp})\ {}_{\parallel}R_{\perp}}{F'(\Theta_j)\ D_{12}} \tag{28}$$

$$T_4 = \frac{{}_{\perp}R_{\parallel}}{{}_{\parallel}R_{\perp}} \tag{29}$$

In terms of the Ts the elements of table 1 are given as:

$$(\lambda_{ij}) = \begin{pmatrix} T_1 S^2 & -T_3 S & T_1 S \\ -T_3 T_4 S & T_2 & -T_3 T_4 \\ -T_1 S & T_3 & -T_1 \end{pmatrix} \tag{30}$$

The list of modes for each segment is terminated by a blank card. A maximum of 30 modes will be used although there is no maximum number which the data deck may contain. The list of segments is terminated by a card with $\rho = 40$. Parameters for each segment are stored sequentially on logical file 3. The number of path segments is limited by the space allocated to this file. Each segment requires 1445 words of storage. After reading these data the program returns for another control card if the option is 1 or 2. If the option is 4, then the program generates the required calculations. Upon completion of these calculations, the program returns to read the next data set starting with the data set identification card. This cycle continues until NRDATA sets have been processed.

<u>START</u> Signals that all input is complete and initiates execution for options 1 and 2.

A sample of how the control cards may be used is shown in figure 3.

SPECIAL CONSIDERATIONS

The maximum value of NRCURV is 4 and the maximum number of modes is 30. If either of these values is exceeded, a message is printed and execution continues using the maximum value.

Option 1: Calculations all begin at the transmitter and end at DMAX. DMAX, DMIN, and XINC are used for the horizontal axis scaling.

Option 2: Scaling for amplitude and phase is done automatically. The range on the horizontal axis is 0° to 360° in orbit angle. If RADIUS = 0.0, only the rotating dipole calculations are made for counterclockwise rotation.

Option 4: NAMELIST input (specifying option 4 and NRDATA) must precede the DATA card. Each set of mode constants must be preceded by an identification card and not by a DATA card. Calculations all begin at transmitter and end at DMAX using the first value of INCL and THETA in each list.

TOTAPE = 1: Unit 2 receives the 500 values of the mode sum as single precision complex values, freq, TLONG, TLAT, RBEAR, POWER, INCL, THETA, TALT, RALT, DMIN, and DMAX (in that order). The output is written in unformatted form.

The procedure for using homogeneous sections along a path is to include a single card in the form 'R XX.XXX' after the appropriate segment data. This indicates that the previous set of mode constants are to be used at the distance given by XX.XXX on the card. As a special case, when running the program for the case of a horizontally homogeneous waveguide, mode constant data are input at 'R 0.0'. This is followed by a single card in the format'R XX.XXX' where XX.XXX is the value of DMAX. Furthermore, the program allows for an instantaneous change in path mode constants. This is accomplished by using the same value of ρ for two consecutive sets of mode constants. This is used for minimizing the discrepancies generated by the program when the WKB assumption is violated, such as for large changes in ground conductivity. An example of the horizontally homogeneous sections is shown in the sample data set of figure 3.

```
NAME
 &DATUM
 IOPT=1,
 INCL=0.,90., THETA=0.,90., NRA=2,
 SIZEX=5., SIZEY=4.,
 &END
DATA
TEST DATA
R  0.0    F 10.0    A 0.0     C 0.0     M 0.0         S 10.0       E 0.0
1 90.0       0.0    1 0.0           -4.70745100-002 0.0               -4.70745100-002
2 90.0       0.0    1 0.0           -2.35372600-002 1.0                 0.0
1 81.93069   0.0    1 1.38439500-002-1.90354300-002 1.38439500-002-1.90354300-002
2 81.93069   0.0    1 6.92197500-003-9.51771500-003 1.0                 0.0

R  5.0
R  5.0    F 10.0    A 0.0     C 0.0     M 0.0         S 10.0       E 0.0
1 90.0       0.0    1 0.0           -4.70745100-003 0.0               -4.70745100-003
2 90.0       0.0    1 0.0           -2.35372600-003 1.0                 0.0
1 81.93069   0.0    1 1.38439500-003-1.90354300-003 1.38439500-003-1.90354300-003
2 81.93069   0.0    1 6.92197500-004-9.51771500-004 1.0                 0.0

R 10.0
R 40.
START
NAME
 &DATUM
 ICOMP=2,
 NPPLOT=1,
 INCL=0.,90.,90.,THETA=0.,0.,90.,NRA=3,NRCURV=3,
 &END
START
NAME
 &DATUM
 ICOMP=1,
 IOPT=2,
 INCL=45.,
 DIST=4.9,5.1, NRD=2,
 &END
START
NAME
 &DATUM IOPT=4,NRDATA=2,NPPLOT=0,&END
DATA
TEST DATA
R  0.0    F 10.0    A 0.0     C 0.0     M 0.0         S 10.0       E 0.0
1 90.0       0.0    1 0.0           -4.70745100-002 0.0               -4.70745100-002
2 90.0       0.0    1 0.0           -2.35372600-002 1.0                 0.0
1 81.93069   0.0    1 1.38439500-002-1.90354300-002 1.38439500-002-1.90354300-002
2 81.93069   0.0    1 6.92197500-003-9.51771500-003 1.0                 0.0

R  5.0
R  5.0    F 10.0    A 0.0     C 0.0     M 0.0         S 10.0       E 0.0
1 90.0       0.0    1 0.0           -4.70745100-003 0.0               -4.70745100-003
2 90.0       0.0    1 0.0           -2.35372600-003 1.0                 0.0
1 81.93069   0.0    1 1.38439500-003-1.90354300-003 1.38439500-003-1.90354300-003
2 81.93069   0.0    1 6.92197500-004-9.51771500-004 1.0                 0.0

R 10.0
R 40.
TEST DATA WITH ALL AMPLITUDES REDUCED BY FACTOR OF 10
R  0.0    F 10.0    A 0.0     C 0.0     M 0.0         S 10.0       E 0.0
1 90.0       0.0    1 0.0           -4.70745100-003 0.0               -4.70745100-003
2 90.0       0.0    1 0.0           -2.35372600-003 1.0                 0.0
1 81.93069   0.0    1 1.38439500-003-1.90354300-003 1.38439500-003-1.90354300-003
2 81.93069   0.0    1 6.92197500-004-9.51771500-004 1.0                 0.0

R  5.0
R  5.0    F 10.0    A 0.0     C 0.0     M 0.0         S 10.0       E 0.0
1 90.0       0.0    1 0.0           -4.70745100-004 0.0               -4.70745100-004
2 90.0       0.0    1 0.0           -2.35372600-004 1.0                 0.0
1 81.93069   0.0    1 1.38439500-004-1.90354300-004 1.38439500-004-1.90354300-004
2 81.93069   0.0    1 6.92197500-005-9.51771500-005 1.0                 0.0

R 10.0
R 40.
↑________ Card column 1
```

Figure 3. Sample data deck

In order to facilitate mode matching across segment boundaries, a missing mode can be indicated by a pair of filler cards inserted in the deck where the mode would have appeared. This pair of cards must contain a non-zero eigen-angle value. Typically the eigenangle is the value from some previous segment which had the mode. The rest of each of the cards is blank.

EXAMPLE DATA

The data listed in figure 3 exercise the program in most of its options. The test data are fictitious. There are only two modes; their attenuation rate, phase velocity relative to the speed of light, and complex excitation factor Λ_{zz} are given in table 2.

Mode	Attenuation Rate dB/Mm	Phase velocity/c	$\lvert\Lambda_{zz}\rvert$ dB	ϕ_{zz} in degrees
1	0	1.00	0	0
2	0	1.01	-6	36

Table 2. Test data mode parameters

These modes produce interference minima at 3 Mm intervals. The values of the Ts of equations 28-31 are defined such that $\Lambda_{zz} = \Lambda_{yy} = \Lambda_{xx} = \Lambda_{xz} = \Lambda_{zx}$ and $\Lambda_{yz} = \Lambda_{zy} = \Lambda_{xy} = \Lambda_{yx} = \frac{1}{2}\Lambda_{zz}$ for each mode. Thus, a horizontal broadside antenna produces fields which are the same amplitude as produced by a vertical antenna. In figure 3, lines 1-6 are the NAMELIST input data specifying two transmitting antenna orientations: vertical and horizontal broadside. Lines 7-23 are the propagation path constants. Lines 15 and 22 illustrate the use of horizontally homogeneous segments. The first two pages of output for the calculations specified in lines 1-24 are shown in figures 4 and 5. In figure 4 we see the list of segment parameter cards after the control card DATA. After the control card START we see a listing of the mode parameters for each

```
NAME
 $DATUM
IOPT =          1,ICOMP =          1,TALT = .00000000     ,RALT = .00000000     ,POWER = .10000000+001,TOTAPE =          0,
TLONG = .00000000     ,TLAT = .00000000     ,RBEAR = .00000000     ,SIZEX = .50000000+001,SIZEY = .40000000+001,SIZEX1 = .10000000+002,
SIZEX2 = .10000000+001,SIZEY1 = .80000000+001,SIZEY2 = .40000000+001,AMPMAX = .70000000+002,AMPMIN =-.10000000+002,
AMPINC = .10000000+002,PHSMAX = .36000000+003,PHSMIN =-.36000000+003,PHSINC = .90000000+002,DMAX = .10000000+002,
DMIN = .00000000     ,XINC = .10000000+001,NRCURV =          4,NPRINT =          1,NAPLOT =          1,NPPLOT =          0,
NPDIFF =          0,RADIUS = .00000000     ,
DIST = .10000000+001, .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     ,
 .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     ,
 .00000000     , .00000000     , .00000000     , .00000000     ,NRD =          1,
INCL = .00000000     , .90000000+002, .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     ,
 .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     ,
 .00000000     , .00000000     , .00000000     , .00000000     ,
THETA = .00000000     , .90000000+002, .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     ,
 .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     , .00000000     ,
 .00000000     , .00000000     , .00000000     , .00000000     ,NRA =          2,NRDATA =          1
$END

DATA

TEST DATA

R    .000 F 10.0000 A    .000 C    .000 M   .000 S 1.000+001 E    .0 MODES  2

R   5.000 F    .0000 A    .000 C    .000 M   .000 S   .000    E    .0

         USING DATA FROM PREVIOUS RHO

R   5.000 F 10.0000 A    .000 C    .000 M   .000 S 1.000+001 E    .0 MODES  2

R  10.000 F    .0000 A    .000 C    .000 M   .000 S   .000    E    .0

         USING DATA FROM PREVIOUS RHO

START

 Z COMPONENT OPTION 1

RHO =    .000  MODE  ATTEN   V/C        VERTICAL         BROADSIDE        END FIRE          V        B        E
                 1    .000  1.00000    -2.691   .000   -8.712  3.142   -75.238 -2.356    -2.69    -8.71   -75.24
                 2    .000  1.01000    -8.885   .629  -14.819 -2.513   -81.345 -1.727    -8.88   -14.82   -81.35

RHO =   5.000  MODE  ATTEN   V/C        VERTICAL         BROADSIDE        END FIRE          V        B        E
                 1    .000  1.00000    -2.691   .000   -8.712  3.142   -75.238 -2.356    -2.69    -8.71   -75.24
                 2    .000  1.01000    -8.885   .629  -14.819 -2.513   -81.345 -1.727    -8.88   -14.82   -81.35

RHO =   5.000  MODE  ATTEN   V/C        VERTICAL         BROADSIDE        END FIRE          V        B        E
                 1    .000  1.00000   -22.691   .000  -28.712  3.142   -95.238 -2.356   -12.69   -18.71   -85.24
                 2    .000  1.01000   -28.885   .629  -34.819 -2.513  -101.345 -1.727   -18.88   -24.82   -91.35

RHO =  10.000  MODE  ATTEN   V/C        VERTICAL         BROADSIDE        END FIRE          V        B        E
                 1    .000  1.00000   -22.691   .000  -28.712  3.142   -95.238 -2.356   -12.69   -18.71   -85.24
                 2    .000  1.01000   -28.885   .629  -34.819 -2.513  -101.345 -1.727   -18.88   -24.82   -91.35
```

Figure 4. First page of output produced by lines 1-24 of sample deck

Z COMP INCL = .000 THETA = .000 TALT = .0 RALT = .0

DIST	AMPLITUDE	PHASE	DIST	AMPLITUDE	PHASE	DIST	AMPLITUDE	PHASE	DIST	AMPLITUDE	PHASE
.000	104.7406	.0000	2.520	54.1079	82.0440	5.040	39.3953	64.9618	7.560	33.4001	64.8874
.020	74.7357	102.4070	2.540	54.1079	82.8111	5.060	39.5119	65.4817	7.580	33.6268	64.0587
.040	71.6690	103.1432	2.560	54.1047	83.5812	5.080	39.6241	66.0210	7.600	33.8539	63.3351
.060	69.8481	103.8734	2.580	54.0985	84.3539	5.100	39.7320	66.5785	7.620	34.0802	62.7111
.080	68.5352	104.5970	2.600	54.0892	85.1289	5.120	39.8356	67.1530	7.640	34.3050	62.1809
.100	67.4988	105.3135	2.620	54.0768	85.9059	5.140	39.9350	67.7436	7.660	34.5274	61.7391
.120	66.6361	106.0225	2.640	54.0614	86.6846	5.160	40.0303	68.3492	7.680	34.7470	61.3800
.140	65.8921	106.7233	2.660	54.0429	87.4645	5.180	40.1216	68.9689	7.700	34.9631	61.0985
.160	65.2338	107.4155	2.680	54.0214	88.2455	5.200	40.2087	69.6018	7.720	35.1755	60.8894
.180	64.6401	108.0984	2.700	53.9968	89.0272	5.220	40.2920	70.2472	7.740	35.3837	60.7480
.200	64.0965	108.7713	2.720	53.9692	89.8092	5.240	40.3713	70.9041	7.760	35.5876	60.6698
.220	63.5926	109.4337	2.740	53.9385	90.5913	5.260	40.4467	71.5720	7.780	35.7869	60.6504
.240	63.1209	110.0848	2.760	53.9047	91.3732	5.280	40.5184	72.2501	7.800	35.9816	60.6859
.260	62.6754	110.7239	2.780	53.8679	92.1546	5.300	40.5863	72.9378	7.820	36.1714	60.7726
.280	62.2516	111.3501	2.800	53.8281	92.9351	5.320	40.6504	73.6345	7.840	36.3564	60.9071
.300	61.8459	111.9627	2.820	53.7851	93.7144	5.340	40.7109	74.3395	7.860	36.5364	61.0860
.320	61.4553	112.5607	2.840	53.7391	94.4922	5.360	40.7678	75.0524	7.880	36.7115	61.3065
.340	61.0776	113.1432	2.860	53.6899	95.2682	5.380	40.8210	75.7727	7.900	36.8817	61.5658
.360	60.7106	113.7092	2.880	53.6377	96.0421	5.400	40.8707	76.4997	7.920	37.0470	61.8612
.380	60.3526	114.2575	2.900	53.5823	96.8135	5.420	40.9169	77.2330	7.940	37.2073	62.1905
.400	60.0023	114.7870	2.920	53.5237	97.5822	5.440	40.9596	77.9723	7.960	37.3629	62.5513
.420	59.6583	115.2965	2.940	53.4620	98.3476	5.460	40.9988	78.7170	7.980	37.5136	62.9416
.440	59.3197	115.7846	2.960	53.3971	99.1095	5.480	41.0347	79.4666	8.000	37.6596	63.3596
.460	58.9854	116.2498	2.980	53.3289	99.8676	5.500	41.0671	80.2210	8.020	37.8008	63.8034
.480	58.6547	116.6907	3.000	53.2575	100.6214	5.520	41.0961	80.9795	8.040	37.9375	64.2714
.500	58.3268	117.1055	3.020	53.1829	101.3705	5.540	41.1218	81.7418	8.060	38.0695	64.7620
.520	58.0010	117.4925	3.040	53.1049	102.1146	5.560	41.1441	82.5077	8.080	38.1971	65.2739
.540	57.6768	117.8497	3.060	53.0236	102.8531	5.580	41.1631	83.2766	8.100	38.3202	65.8057
.560	57.3537	118.1751	3.080	52.9390	103.5858	5.600	41.1788	84.0484	8.120	38.4389	66.3562
.580	57.0312	118.4665	3.100	52.8509	104.3120	5.620	41.1913	84.8225	8.140	38.5533	66.9241
.600	56.7090	118.7213	3.120	52.7594	105.0314	5.640	41.2004	85.5988	8.160	38.6634	67.5085
.620	56.3866	118.9371	3.140	52.6644	105.7434	5.660	41.2063	86.3768	8.180	38.7694	68.1083
.640	56.0637	119.1110	3.160	52.5659	106.4475	5.680	41.2090	87.1563	8.200	38.8712	68.7225
.660	55.7402	119.2401	3.180	52.4638	107.1432	5.700	41.2084	87.9369	8.220	38.9689	69.3503
.680	55.4157	119.3210	3.200	52.3581	107.8298	5.720	41.2046	88.7183	8.240	39.0626	69.9908
.700	55.0902	119.3503	3.220	52.2488	108.5067	5.740	41.1975	89.5002	8.260	39.1523	70.6432
.720	54.7635	119.3242	3.240	52.1357	109.1734	5.760	41.1872	90.2824	8.280	39.2381	71.3069
.740	54.4356	119.2388	3.260	52.0189	109.8290	5.780	41.1737	91.0644	8.300	39.3201	71.9811
.760	54.1065	119.0897	3.280	51.8982	110.4729	5.800	41.1569	91.8460	8.320	39.3982	72.6650
.780	53.7762	118.8724	3.300	51.7737	111.1043	5.820	41.1369	92.6269	8.340	39.4726	73.3582
.800	53.4451	118.5820	3.320	51.6452	111.7224	5.840	41.1137	93.4067	8.360	39.5432	74.0601
.820	53.1133	118.2136	3.340	51.5128	112.3263	5.860	41.0872	94.1851	8.380	39.6102	74.7699
.840	52.7812	117.7617	3.360	51.3763	112.9151	5.880	41.0574	94.9619	8.400	39.6735	75.4873
.860	52.4493	117.2209	3.380	51.2356	113.4877	5.900	41.0244	95.7367	8.420	39.7332	76.2117
.880	52.1182	116.5855	3.400	51.0908	114.0431	5.920	40.9881	96.5091	8.440	39.7894	76.9426
.900	51.7888	115.8499	3.420	50.9417	114.5802	5.940	40.9484	97.2789	8.460	39.8420	77.6796
.920	51.4618	115.0085	3.440	50.7884	115.0978	5.960	40.9055	98.0456	8.480	39.8911	78.4222
.940	51.1386	114.0559	3.460	50.6306	115.5945	5.980	40.8592	98.8090	8.500	39.9368	79.1699
.960	50.8204	112.9874	3.480	50.4684	116.0689	6.000	40.8096	99.5686	8.520	39.9790	79.9224
.980	50.5086	111.7986	3.500	50.3017	116.5196	6.020	40.7566	100.3241	8.540	40.0178	80.6794
1.000	50.2052	110.4865	3.520	50.1304	116.9449	6.040	40.7002	101.0752	8.560	40.0532	81.4402
1.020	49.9120	109.0490	3.540	49.9545	117.3431	6.060	40.6403	101.8213	8.580	40.0852	82.2048
1.040	49.6311	107.4860	3.560	49.7739	117.7123	6.080	40.5770	102.5621	8.600	40.1139	82.9725
1.060	49.3648	105.7993	3.580	49.5885	118.0506	6.100	40.5102	103.2971	8.620	40.1393	83.7432
1.080	49.1156	103.9932	3.600	49.3984	118.3556	6.120	40.4399	104.0259	8.640	40.1613	84.5164

Figure 5. Second page of output produced by lines 1-24 of sample deck

segment. The headings "VERTICAL", "BROADSIDE", and "END FIRE" are for the magnitude in dB and phase in radians of the components of the excitation factors. The headings "V", "B", and "E" are for the relative magnitude of these components at the beginning of each slab. This list appears only when ICOMP, TALT, RALT, or the mode parameters are changed. In figure 5 we see the list of computed amplitude in dB above 1)V/m and phase relative to the speed of light in degrees printed as functions of distance in Mm. This list is preceded by a line of print indicating the received field component, the transmitting antenna orientation, and the altitudes of the transmitter and receiver. The plots for these calculations are shown in figure 6.

Lines 25-31 of figure 3 call for the E_y fields and phase plots. Three transmitting antenna orientations are specified. The resulting plots of the amplitude and relative phase are shown in figures 7a and 7b, respectively. There are apparently only two curves in figure 7a because the amplitude of E_y from a vertical source is the same as that from a horizontal end-fire source.

Lines 32-39 of figure 3 call for a rotating transmitter antenna inclined at 45°. The calculations are to be made for two distances. The first page of printout generated by these lines is shown in figure 8. The mean signal and the standard deviation of the signal for the rotation are printed at each distance. The table of amplitude and relative phase as a function of rotation angle, R, appears as a result of NPRINT = 1. The plots resulting from the calculations are shown in figure 9.

Lines 40-74 of figure 3 illustrate the IOPT = 4 option. The plots resulting from these calculations are shown in figure 10.

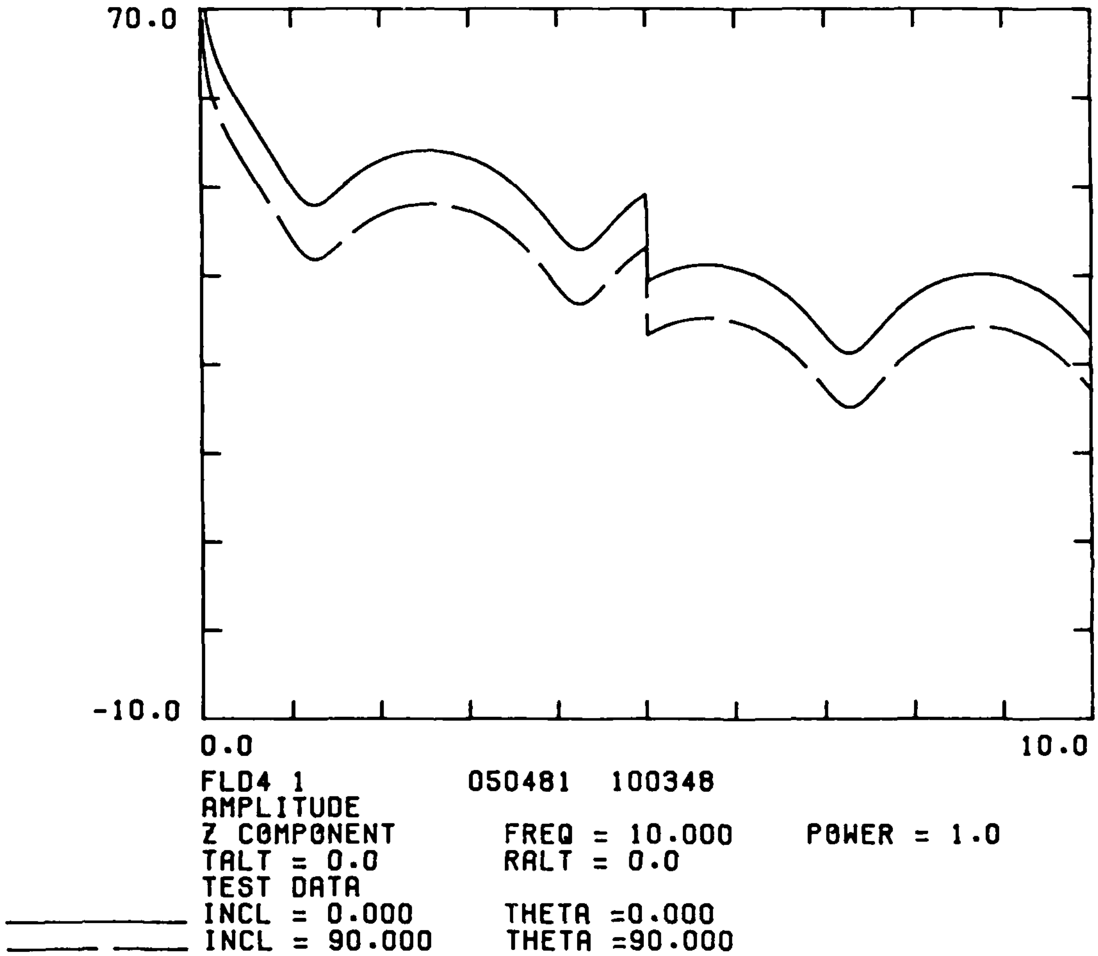


Figure 6. Plotted output generated by lines 1-24 of the sample deck

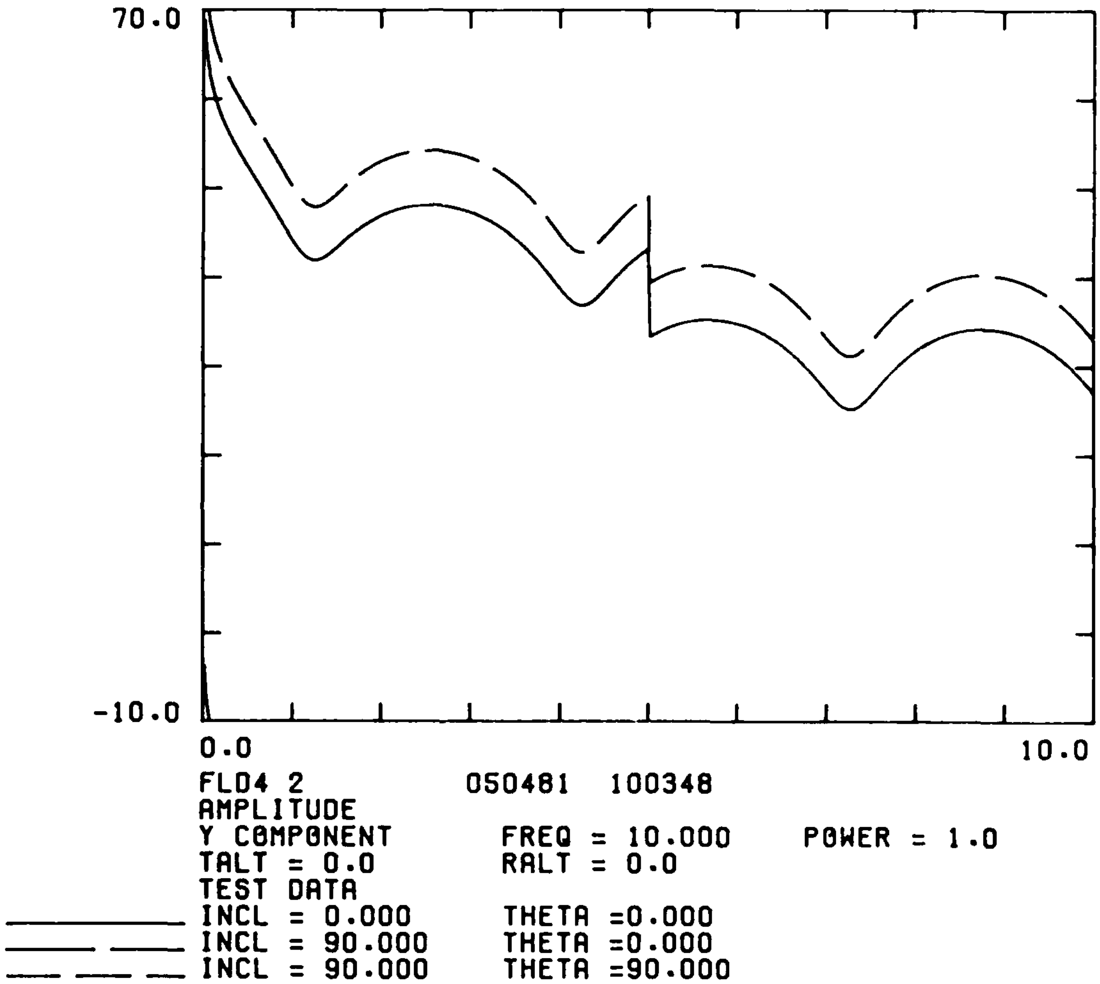


Figure 7a. Plotted amplitude output generated by lines 25-31 of the sample deck.

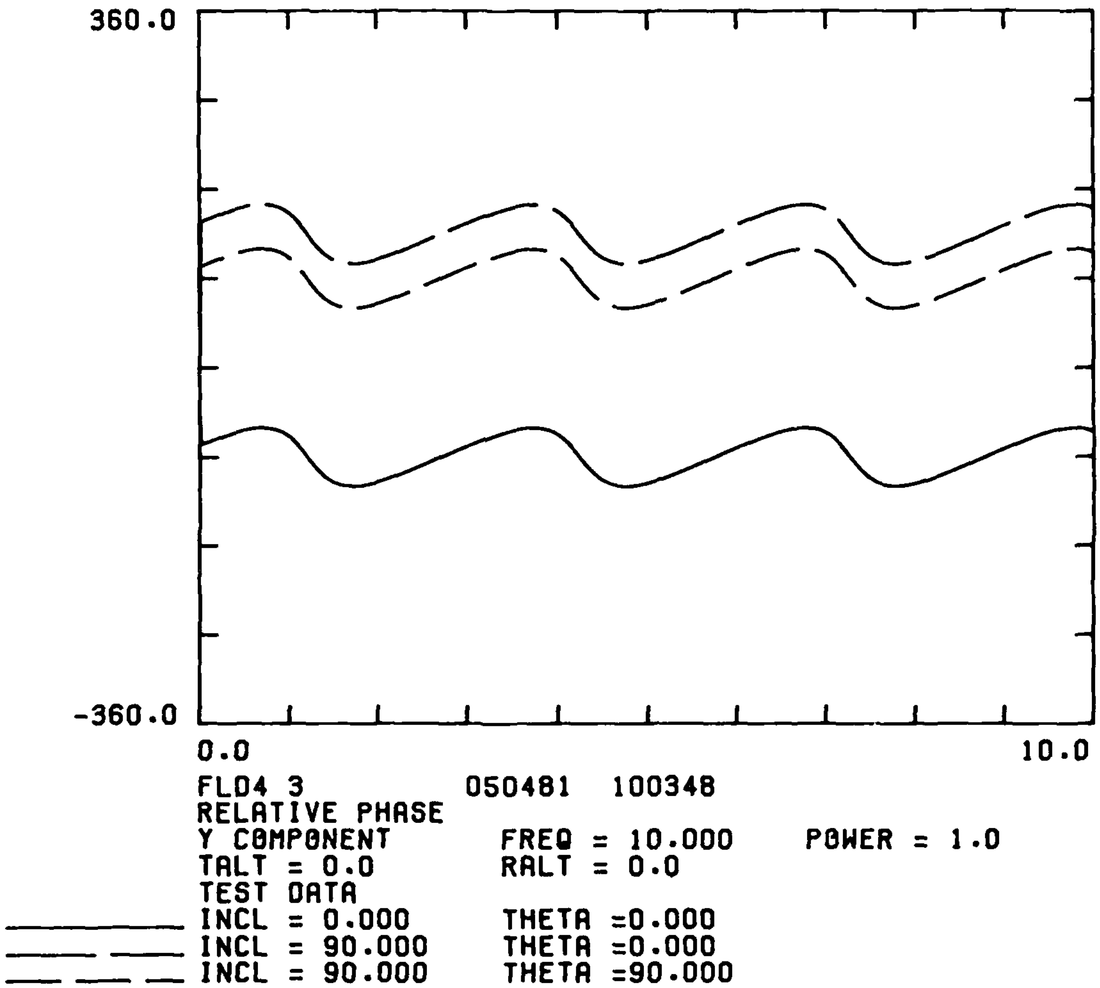


Figure 7b. Plotted relative phase output generated by lines 25-31 of the sample deck

```
NAME
 $DATUM
IOPT =           2,ICOMP =           1,TALT = .00000000    ,RALT = .00000000    ,POWER = .10000000+001,TOTAPE =           0,
TLONG = .00000000    ,TLAT = .00000000    ,RBEAR = .00000000    ,SIZEX =-.10000000+001,SIZEY =-.10000000+001,SIZEX1 = .50000000+001,
SIZEX2 = .10000000+001,SIZEY1 = .40000000+001,SIZEY2 = .40000000+001,AMPMAX = .70000000+002,AMPMIN =-.10000000+002,
AMPINC = .10000000+002,PHSMAX = .36000000+003,PHSMIN =-.36000000+003,PHSINC = .90000000+002,DMAX = .10000000+002,
DMIN = .00000000    ,XINC = .10000000+001,NRCURV =           3,NPRINT =           1,NAPLOT =           1,NPPLOT =           1,
NPDIFF =           0,RADIUS = .00000000    ,
DIST = .49000000+001, .51000000+001, .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    ,
 .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    ,
 .00000000    , .00000000    , .00000000    , .00000000    ,NRD =           2,
INCL = .45000000+002, .90000000+002, .90000000+002, .00000000    , .00000000    , .00000000    , .00000000    , .00000000    ,
 .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    ,
 .00000000    , .00000000    , .00000000    , .00000000    ,
THETA = .00000000    , .00000000    , .90000000+002, .00000000    , .00000000    , .00000000    , .00000000    , .00000000    ,
 .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    , .00000000    ,
 .00000000    , .00000000    , .00000000    , .00000000    ,NRA =           3,NRDATA =           1
$END

START

 Z COMPONENT OPTION 2

Z COMP   DIST =    4.900 INCL =   45.000
```

THETA	AMPLITUDE	PHASE	THETA	AMPLITUDE	PHASE	THETA	AMPLITUDE	PHASE	THETA	AMPLITUDE	PHASE
.000	45.4393	61.9779	95.000	39.4417	62.2505	190.000	46.1663	61.9750	285.000	48.8670	61.9001
5.000	45.0517	61.9895	100.000	39.5402	62.2462	195.000	46.5004	61.9654	290.000	48.7897	61.9012
10.000	44.6492	62.0022	105.000	39.7009	62.2382	200.000	46.8149	61.9567	295.000	48.6903	61.9027
15.000	44.2337	62.0160	110.000	39.9193	62.2269	205.000	47.1091	61.9487	300.000	48.5689	61.9047
20.000	43.8077	62.0309	115.000	40.1894	62.2130	210.000	47.3824	61.9414	305.000	48.4254	61.9072
25.000	43.3741	62.0470	120.000	40.5045	62.1969	215.000	47.6345	61.9349	310.000	48.2600	61.9102
30.000	42.9364	62.0642	125.000	40.8573	62.1793	220.000	47.8652	61.9290	315.000	48.0727	61.9138
35.000	42.4987	62.0823	130.000	41.2404	62.1608	225.000	48.0742	61.9237	320.000	47.8635	61.9179
40.000	42.0659	62.1013	135.000	41.6466	62.1418	230.000	48.2614	61.9190	325.000	47.6327	61.9228
45.000	41.6434	62.1210	140.000	42.0692	62.1228	235.000	48.4266	61.9149	330.000	47.3804	61.9282
50.000	41.2373	62.1409	145.000	42.5021	62.1042	240.000	48.5699	61.9113	335.000	47.1069	61.9344
55.000	40.8544	62.1608	150.000	42.9398	62.0861	245.000	48.6912	61.9082	340.000	46.8126	61.9414
60.000	40.5019	62.1801	155.000	43.3774	62.0689	250.000	48.7904	61.9056	345.000	46.4980	61.9491
65.000	40.1872	62.1983	160.000	43.8110	62.0525	255.000	48.8675	61.9035	350.000	46.1636	61.9578
70.000	39.9174	62.2147	165.000	44.2369	62.0371	260.000	48.9226	61.9018	355.000	45.8104	61.9673
75.000	39.6995	62.2287	170.000	44.6523	62.0227	265.000	48.9557	61.9006	360.000	45.4393	61.9779
80.000	39.5392	62.2397	175.000	45.0548	62.0093	270.000	48.9666	61.8998			
85.000	39.4412	62.2472	180.000	45.4423	61.9970	275.000	48.9555	61.8995			
90.000	39.4084	62.2508	185.000	45.8132	61.9855	280.000	48.9223	61.8996			

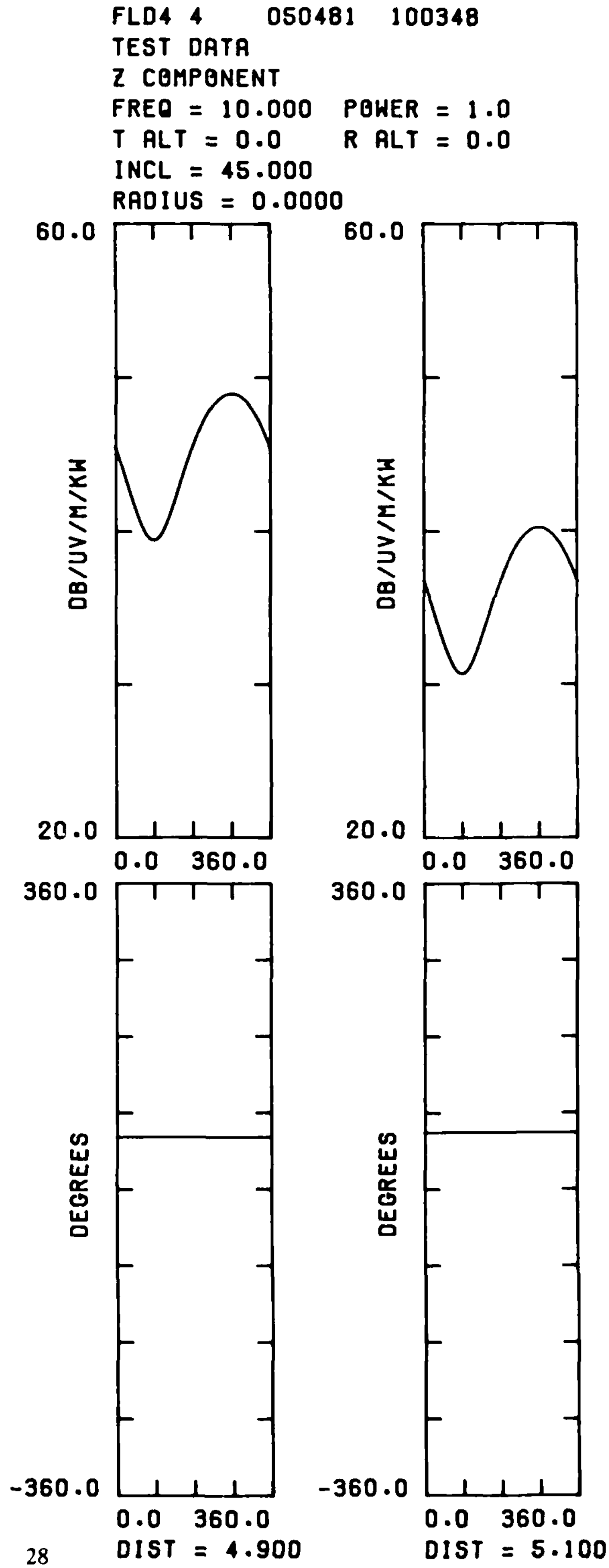
DIST	MEAN A	STD
4.900	44.845	3.328

Z COMP   DIST =   5.100 INCL =   45.000

THETA	AMPLITUDE	PHASE	THETA	AMPLITUDE	PHASE	THETA	AMPLITUDE	PHASE	THETA	AMPLITUDE	PHASE
.000	36.7202	66.5690	95.000	30.7138	66.7683	190.000	37.4479	66.5721	285.000	40.1508	66.5154
5.000	36.3322	66.5773	100.000	30.8125	66.7657	195.000	37.7823	66.5651	290.000	40.0734	66.5160
10.000	35.9293	66.5863	105.000	30.9736	66.7604	200.000	38.0971	66.5586	295.000	39.9740	66.5169
15.000	35.5133	66.5961	110.000	31.1924	66.7527	205.000	38.3915	66.5528	300.000	39.8524	66.5182
20.000	35.0868	66.6068	115.000	31.4630	66.7430	210.000	38.6650	66.5474	305.000	39.7089	66.5198

Figure 8. First page of printout generated by lines 32-39 of the sample deck

Figure 9. Plotted output generated by lines 32-39 of the sample deck



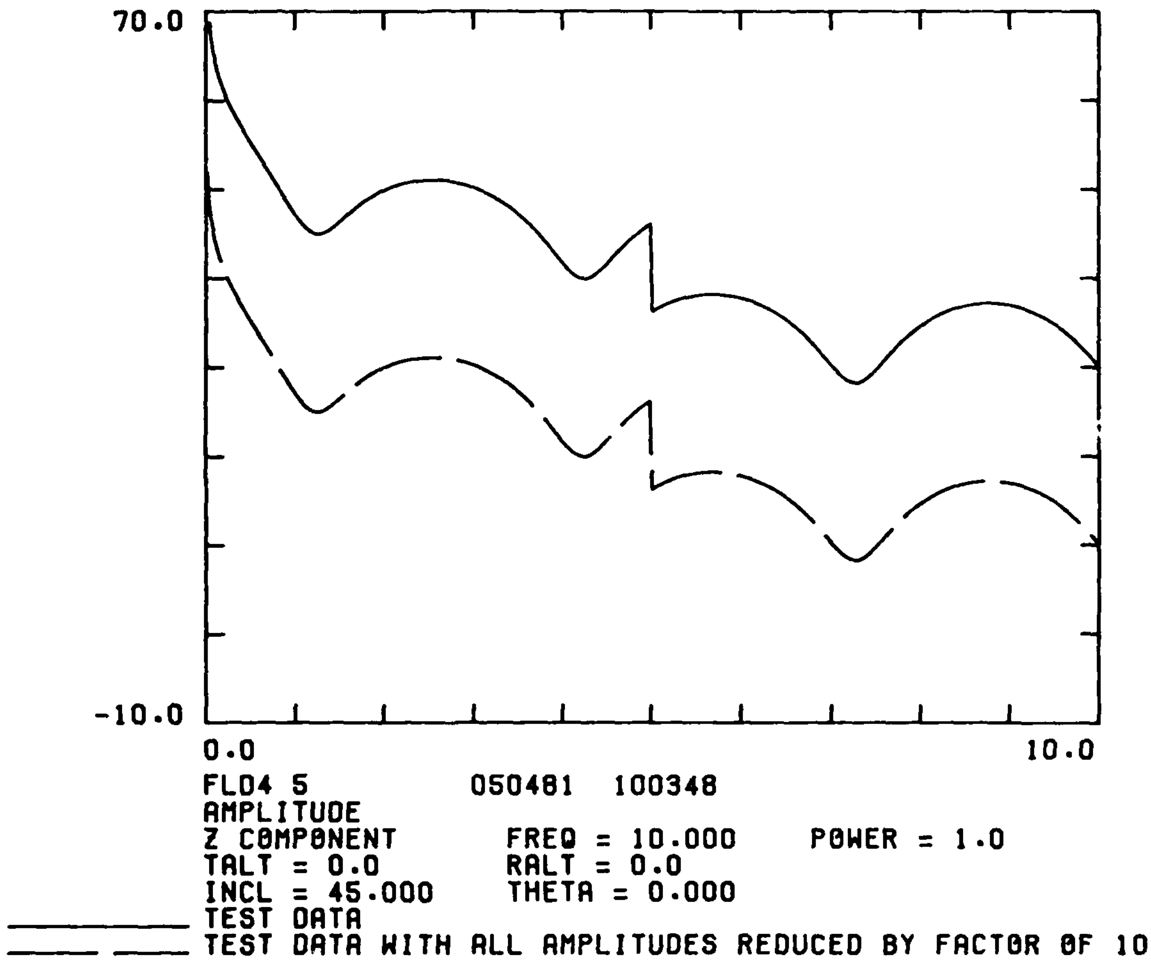


Figure 10. Plotted output generated by lines 40-74 of the sample deck

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8. Wait, JR, Two-dimensional Treatment of Mode Theory of the Propagation of VLF Radio Waves, Radio Science Journal of Research, NBS/USNC-URSI Vol 68D, No 1, 1964

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APPENDIX: PROGRAM LISTING

```
C
C     FLD4:  WKB MODE SUM
C
      COMMON/INPUT/STP(30),TP(30),AV(30),EX(3,3,30),EK,ALPHA,SIGMA,EPSR,
     $       MODES,RHO
      COMMON/ONE/RHOMAX,RHOD,NEWD,NEWHGT,NEWHGR,NEWP
      COMMON/IDENT/ID(20),FREQ,TALT,RALT,ICOMP,ZYX,IOPT,THTA,INCANG,DST,
     $       RADIUS,POWER
      COMMON/DIMEN/XLNG,YLNG,AMPMAX,AMPMIN,AMPINC,PHSMAX,PHSMIN,
     $       PHSINC,DMAX,DMIN,XINC,TMAX,TMIN,TINC,
     $       NRCURV,NAPLOT,NPPLOT,NPDIFF,NPRINT
      COMMON/OUTPUT/XY(501),AMP(501),PHS(501),NRPTS,NRCRVS,NRPLTS,
     $       DATE,TIME
      COMMON NOMODE(30)
C
      COMPLEX*16 TP,STP,AV,EX,MIK,RATIO,TMP1,TMP2,TMP3,TMP4
      COMPLEX* 8 SUMOUT
      REAL*8 DTR/1.745329252D-2/,ALPHA/3.14D-4/,SIGMA,EPSR,
     $       SC,SINIO,COSIO,CC
      REAL*4 INCL,INCANG,MAGFLD
      INTEGER TOTAPE/0/
      LOGICAL NOMODE
      CHARACTER*8 DATE,TIME
      CHARACTER*4 BCD,NAME,INPT,EXEC,ENDF
      CHARACTER LABEL,ZYX
C
      DIMENSION BCD(20),LABEL(3),RATIO(4),SUMOUT(501),
     $          DIST(20),INCL(20),THETA(20),SINT(73),SC(3,73)
C
      NAMELIST/DATUM/IOPT,ICOMP,TALT,RALT,POWER,TOTAPE,TLONG,TLAT,RBEAR,
     $         SIZEX,SIZEY,
     $         SIZEX1,SIZEX2,SIZEY1,SIZEY2,AMPMAX,AMPMIN,AMPINC,PHSMAX,
     $         PHSMIN,PHSINC,DMAX,DMIN,XINC,NRCURV,NPRINT,NAPLOT,
     $         NPPLOT,NPDIFF,RADIUS,DIST,NRD,INCL,THETA,NRA,NRDATA
C
C...COMMON INITIALIZATION
      DATA AMPMAX/70./,AMPMIN/-10./,PHSMAX/360./,PHSMIN/-360./
      DATA DMAX/10./,DMIN/0./,TMAX/360./,TMIN/0./
      DATA TALT,RALT/0.,0./,ICOMP/1/,RADIUS/0./,POWER/1./
      DATA NRCURV/4/,NAPLOT/1/,NPPLOT/0/,NPDIFF/0/
      DATA NPRINT/1/
      DATA AMPINC/10./,PHSINC/90./,XINC/1./
      DATA ICOMPS/0/,NRCRVS/0/,NRPLTS/0/,NEWD/-1/
C
      DATA INPT/4HDATA/,NAME/4HNAME/,EXEC/4HSTAR/,ENDF/4HENDF/,
     $     LABEL/'Z','Y','X'/,STALT,SRALT/2*-1./,IOPT/1/,NRDATA/1/,
     $     SIZEX /-1./,SIZEY /-1./,
     $     SIZEX1/10./,SIZEY1/ 8./,NRPTS1/501/,
     $     SIZEX2/ 1./,SIZEY2/ 4./,NRPTS2/ 73/,
     $     DIST,INCL,THETA/1.,59*0./,NRD,NRA/2*1/,TLONG,TLAT,RBEAR/3*0./
C
      CALL ADATE(DATE,TIME)
      PRINT 999,DATE,TIME
C
C...READ AND TEST CONTROL CARD
 10   PRINT 1005
```

```
11    READ(5,1001,END=990) BCD
      PRINT 1002,BCD
      IF(BCD(1) .EQ. NAME) GO TO 15
      IF(BCD(1) .EQ. EXEC) GO TO 30
      IF(BCD(1) .EQ. INPT) GO TO 20
      IF(BCD(1) .EQ. ENDF) GO TO 56
      GO TO 910
C
C...READ AND PRINT NAMELIST DATA
15    READ(5,DATUM,END=989)
      PRINT DATUM
      IF(NRCURV .GT. 4) GO TO 908
      IF(SIZEX .LT. 0.) GO TO 160
      GO TO (151,152,912,151),IOPT
151   SIZEX1=SIZEX
      GO TO 159
152   SIZEX2=SIZEX
159   SIZEX=-1.
160   IF(SIZEY .LT. 0.) GO TO 170
      GO TO (161,169,912,161),IOPT
161   SIZEY1=SIZEY
169   SIZEY=-1.
170   IF(SIZEY1 .GT. 8.) GO TO 913
      GO TO 11
C
C...READ PROPAGATION PATH PARAMETERS
C
C...SET COUNTER FOR IOPT=4
20    NDATA=0
200   READ(5,1001,END=989) ID
      PRINT 1002,ID
      REWIND 3
      MNMODE=31
      NR=0
      RHO=-1.
C
C...READ SEGMENT CONSTANTS
21    READ(5,1020,END=989) R,F,A,C,B,S,E
      IF(R .EQ. 40.) GO TO 25
      B=B*10000.
      PRINT 1021,R,F,A,C,B,S,E
      IF(NPRINT .LT. 2) GO TO 210
      PRINT 1221
210   IF(NR .GT. 0) GO TO 22
      FREQ=F
C     WN=2*PI*FREQ/C
      WN=20.958445E0*FREQ
      MIK=CMPLX(0.,-WN)
      EK=682.2408*SQRT(FREQ)
22    NR=NR+1
      IF(RHO .GT. R) GO TO 911
      RHO=R
      RHOMAX=R
C...CHECK IF THIS IS JUST A RHO CARD - FOR HOMOGENEOUS SEGMENT
      IF(S .GT. 0.) GO TO 220
      PRINT 1220
      GO TO 241
```

```
 220    SIGMA=S
        EPSR=E
        AZIM=A
        CODIP=C
        MAGFLD=B
C
C...READ MODE CONSTANTS
        NM=0
 23     READ(5,1023,END=989) INDX1,TR1,TI1,TMP1,TMP2
        IF(TR1 .EQ. 0.) GO TO 24
        NM=NM+1
        READ(5,1023,END=989) INDX2,TR2,TI2,TMP3,TMP4
        IF(NPRINT .LT. 2) GO TO 223
        PRINT 1025, NM,INDX1,TR1,TI1,TMP1,TMP2,INDX2,TR2,TI2,TMP3,TMP4
 223    IF(TR1 .NE. TR2 .OR. TI1 .NE. TI2) GO TO 919
        IF(INDX1 .EQ. INDX2) GO TO 919
        IF(INDX1 .NE. 1 .AND. INDX1 .NE. 2) GO TO 919
        IF(INDX2 .NE. 1 .AND. INDX2 .NE. 2) GO TO 919
C...TEST IF MAXIMUM NUMBER OF MODES EXCEEDED
        IF(NM .GT. 30) GO TO 23
        TP(NM)=CMPLX(TR1,TI1)
        STP(NM)=CDSIN(TP(NM)*DTR)
        AV(NM)=MIK*(STP(NM)-1.D0)
C...TEST FOR MISSING MODE
        NOMODE(NM)=.FALSE.
        IF(CDABS(TMP1) .NE. 0.D0) GO TO 230
        NOMODE(NM)=.TRUE.
        TMP1=1.D-20
        TMP2=1.D-20
        TMP3=1.D-20
        TMP4=1.D0
 230    RATIO(2*INDX1-1)=TMP1
        RATIO(2*INDX1  )=TMP2
        RATIO(2*INDX2-1)=TMP3
        RATIO(2*INDX2  )=TMP4
C...DEFINE EXCITATION FACTOR MATRIX
        EX(1,1,NM)=    RATIO(1)*STP(NM)**2
        EX(2,1,NM)=   -RATIO(3)*RATIO(4)*STP(NM)
        EX(3,1,NM)=   -RATIO(1)*STP(NM)
        EX(1,2,NM)=   -RATIO(3)*STP(NM)
        EX(2,2,NM)=    RATIO(2)
        EX(3,2,NM)=    RATIO(3)
        EX(1,3,NM)=    RATIO(1)*STP(NM)
        EX(2,3,NM)=   -RATIO(3)*RATIO(4)
        EX(3,3,NM)=   -RATIO(1)
        GO TO 23
 24     IF(NM .EQ. 0) GO TO 909
        IF(NPRINT .NE. 2) PRINT 1026,NM
        IF(NM .GT. 30 .OR. NM .GT. MNMODE) PRINT 1014
 241    MODES=MIN0(30,NM)
        MODES=MIN0(MODES,MNMODE)
C
C...SAVE SEGMENT DATA
        WRITE(3) STP,TP,AV,EX,SIGMA,EPSR,RHO,MODES,NOMODE
        MNMODE=MODES
        GO TO 21
 25     IF(NR .LE. 1) GO TO 915
```

```
      NEWD=1
      NDATA=NDATA+1
      IF(IOPT .EQ. 4) GO TO 30
      GO TO 11
C
30    IF(NEWD .EQ. -1) GO TO 916
      ZYX=LABEL(ICOMP)
      PRINT 1004,ZYX,IOPT
C
C...CHECK IF NEW HEIGHT GAIN CALCULATIONS ARE NEEDED
      NEWP=0
      IF(ICOMP .EQ. ICOMPS .AND. NEWD .EQ. 0) GO TO 38
      NEWP=1
      ICOMPS-'COMP
38    IF(TALT .EQ. STALT .AND. NEWD .EQ. 0) GO TO 40
      NEWP=1
      NEWHGT=1
      STALT=TALT
40    IF(RALT .EQ. SRALT .AND. NEWD .EQ. 0) GO TO 41
      NEWP=1
      NEWHGR=1
      SRALT=RALT
C
C...BRANCH TO OPTION
41    GO TO (50,60.912,90),IOPT
C
C...FIELDS VS DISTANCE PARAMETRIC IN INCL AND THETA
50    NRPTS=NRPTS1
      XLNG=SIZEX1
      YLNG=SIZEY1
      XYMAX=AMIN1(DMAX,RHOMAX)
      DINC=(XYMAX-DMIN)/(NRPTS-1)
      XY(1)=DMIN
      DO 52 J=2,NRPTS
52    XY(J)=XY(J-1)+DINC
C...LOOP OVER ANTENNA ORIENTATIONS
      DO 55 I=1,NRA
      INCANG=INCL(I)
      THTA=THETA(I)
      SC(1,1)=DCOS(INCANG*DTR)
      SINIO=DSIN(INCANG*DTR)
      SC(2,1)=SINIO*DSIN(THTA*DTR)
      SC(3,1)=SINIO*DCOS(THTA*DTR)
      RHOD=0.
C...LOOP OVER DISTANCE
      DO 54 J=1,NRPTS
      CALL SUMS(J,XY(J),AMP(J),PHS(J),SUMOUT(J),SC(1,1),0.)
54    CONTINUE
      NEWP=0
      NEWD=0
      NEWHGT=0
      NEWHGR=0
55    CALL POUT1(I.NRA)
      IF(TOTAPE .EQ. 1) WRITE(2) SUMOUT,FREQ,TLONG,TLAT,RBEAR,POWER,
     $   INCANG,THTA,TALT,RALT,DMIN,XYMAX
      IF(DMAX .LT. RHOMAX) NEWHGR=1
      GO TO 10
```

```
50    IF(TOTAPE .EQ. 1) END FILE 2
      GO TO 11
C
C...FIELDS VS THETA PARAMETRIC IN DISTANCE
60    NRPTS=NRPTS2
      XLNG=SIZEX2
      YLNG=4.
      IMAX=NRD-1
      IF(NRD .EQ. 1) GO TO 420
C...MAKE SURE DISTANCES ARE IN ORDER OF INCREASING VALUE
      DO 42 I=1,IMAX
      JMIN=I+1
      DO 42 J=JMIN,NRD
      IF(DIST(J) .GT. DIST(I)) GO TO 42
      TEMPA=DIST(J)
      DIST(J)=DIST(I)
      DIST(I)=TEMPA
42    CONTINUE
C...MAKE SURE DISTANCES ARE NOT BEYOND END OF DATA
420   DO 43 J=1,NRD
      IF(DIST(J) .LE. RHOMAX) GO TO 43
      NRD2=J-1
      IF(NRD2 .EQ. 0) GO TO 421
      PRINT 1017,RHOMAX
      GO TO 44
421   PRINT 1018
      GO TO 10
43    CONTINUE
C
C...SET UP ANTENNA ORIENTATION PARAMETERS
      NRD2=NRD
44    INCANG=INCL(1)
      SINIO=DSIN(INCANG*DTR)
      COSIO=DCOS(INCANG*DTR)
      TINC=(TMAX-TMIN)/(NRPTS-1)
      XY(1)=0.
      SINT(1)=0.
      SC(1,1)=COSIO
      SC(2,1)=0.D0
      SC(3,1)=SINIO
      DO 61 J=2,NRPTS
      XY(J)=XY(J-1)+TINC
      SINT(J)=DSIN(XY(J)*DTR)
      SC(1,J)=COSIO
      SC(2,J)=SINIO*DSIN(XY(J)*DTR)
61    SC(3,J)=SINIO*DCOS(XY(J)*DTR)
C
C...SET UP PLOT
      CALL PLOT(1.5,.5,-3)
      NEWP=0
      RHOD=0.
      IF(NPRINT .LT. 1) PRINT 1030
C...LOOP OVER DISTANCES
      DO 68 I=1,NRD2
      DST=DIST(I)
      IF(DST .EQ. 0.) GO TO 68
C...LOOP OVER ORBITS
```

```
      R=0.
      CC= 1.D0
      DO 66 JJ=1,3
C...LOOP OVER ANTENNA AZIMUTHS
      DO 62 J=1,NRPTS
      SC(2,J)=CC*SC(2,J)
62    CALL SUMS(J,DST,AMP(J),PHS(J),SUMOUT(1),SC(1,J),R*SINT(J))
      NEWD=0
      NEWHGT=0
      CALL POUT2(JJ,I)
      IF(JJ .GT. 1) GO TO 65
      SUM1=0.
      DO 63 J=1,NRPTS
63    SUM1=SUM1+AMP(J)
      AM=SUM1/NRPTS
      SUM1=0.
      DO 64 J=1,NRPTS
64    SUM1=SUM1+(AMP(J)-AM)**2
      AS=SQRT(SUM1/(NRPTS-1))
      IF(NPRINT .GT. 0) PRINT 1030
      PRINT 1031,DST,AM,AS
65    IF(RADIUS .EQ. 0.) GO TO 67
      R=RADIUS
      CC=-1.D0
66    CONTINUE
67    CALL PLOT(XLNG+1.,0.,-3)
68    CONTINUE
      CALL PLOT(0.,0.,-4)
      IF(DST .GE. RHOMAX) NEWHGR=0
      GO TO 10
C
C...MULTIPLE DATA FOR SINGLE COMPONENT,TALT,RALT,INCL AND THETA
90    IF(NDATA .GT. 1) GO TO 91
      NRPTS=NRPTS1
      XLNG=SIZEX1
      YLNG=SIZEY1
      INCANG=INCL(1)
      THTA=THETA(1)
      SC(1,1)=DCOS(INCANG*DTR)
      SINI0=DSIN(INCANG*DTR)
      SC(2,1)=SINI0*DSIN(THTA*DTR)
      SC(3,1)=SINI0*DCOS(THTA*DTR)
91    RHOD=0.
      DINC=(AMIN1(DMAX,RHOMAX)-DMIN)/(NRPTS-1)
      XY(1)=DMIN
      DO 92 J=2,NRPTS
92    XY(J)=XY(J-1)+DINC
      DO 94 J=1,NRPTS
      CALL SUMS(J,XY(J),AMP(J),PHS(J),SUMOUT(J),SC(1,1),0.)
94    CONTINUE
      IF(TOTAPE .EQ. 1) WRITE(2) SUMOUT,FREQ,TLONG,TLAT,RBEAR,POWER,
     $   INCANG,THTA,TALT,RALT,DMIN,DMAX
      CALL POUT1(NDATA,NPDATA)
      IF(NDATA .EQ. NRDATA) GO TO 95
      PRINT 1005
      GO TO 200
95    NEWD=0
```

```
      NEWD=0
      NEWHGR=0
      IF(DMAX .GE. RHOMAX) NEWHGR=0
      GO TO 10
C
C...FOR ERROR EXITS
908   PRINT 1008
      GO TO 990
909   PRINT 1009
      GO TO 990
910   PRINT 1010
      GO TO 990
911   PRINT 1011
      GO TO 990
912   PRINT 1012
      GO TO 990
913   PRINT 1013
      GO TO 990
915   PRINT 1015
      GO TO 990
916   PRINT 1016
      GO TO 990
919   PRINT 1019
      PRINT 1025, NM,INDX1,TR1,TI1,TMP1,TMP2,INDX2,TR2,TI2,TMP3,TMP4
      GO TO 990
989   PRINT 998
C...CLOSE PLOT FILE
990   IF(NRCRVS .GT. 0) CALL PLOT(0.,0.,999)
      PRINT 1000,NRCRVS,NRPLTS
      STOP
C
998   FORMAT('0***** END OF DATA SET ON UNIT 5 *****')
999   FORMAT('1ADDITIONAL PLOT IDENTIFICATION:  ',A8,1X,A8)
1000  FORMAT('0END OF JOB:',I4,' CURVES AND',I4,' GRAPHS GENERATED')
1001  FORMAT(20A4)
1002  FORMAT(/1X,20A4)
1003  FORMAT( 1X,20A4)
1004  FORMAT(/1X,A2,' COMPONENT OPTION',I2)
1005  FORMAT('1')
1008  FORMAT(/5(' *'),' NRCURV GT 4')
1009  FORMAT(/5(' *'),' NUMBER OF MODES EQ 0')
1010  FORMAT(/5(' *'),' UNIDENTIFIED CONTROL CARD')
1011  FORMAT(/5(' *'),' INPUT RHO VALUES OUT OF ORDER')
1012  FORMAT(/5(' *'),' NO OPTION NUMBER 3')
1013  FORMAT(/5(' *'),' SIZEY CANNOT BE GT 8')
1014  FORMAT(/5(' *'),' NUMBER OF MODES REDUCED')
1015  FORMAT(/5(' *'),' INSUFFICIENT DATA FOR WKB MODE SUM')
1016  FORMAT(/5(' *'),' NO MODE DATA INPUT')
1017  FORMAT(/5(' *'),' DIST BEYOND ',F7.3,' WILL BE IGNORED')
1018  FORMAT(/5(' *'),' NO USABLE DISTANCE DATA')
1019  FORMAT(/5(' *'),' ERROR IN DATA')
1020  FORMAT(1X,F7.0,3(2X,F8.0),2(2X,E10.0),2X,E5.0)
1021  FORMAT('0R',F7.3,' F',F8.4,' A',F8.3,' C',F8.3,' M',F6.3,
     $       ' S',1PE10.3,' E',0PF5.1)
1023  FORMAT(I1,2F9.0,1X,4E15.0)
1025  FORMAT(10X,I2,3X,I1,0P2F10.5,2(1X,1P2E16.8)/
     $       15X,      I1,0P2F10.5,2(1X,1P2E16.8))
```

```
1026  FORMAT('+',66X,'MODES',I3)
1030  FORMAT('0 DIST      MEAN A      STD')
1031  FORMAT(1X,F6.3,2F10.3)
1220  FORMAT(/11X,'USING DATA FROM PREVIOUS RHO')
1221  FORMAT(/11X,'M  ID    THETA''')
      END
```

```
      SUBROUTINE SUMS(J,D,AMP,PHS,SUMM,T,RSINT)
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/INPUT/STP(30),TP(30),AV1(30),EX(3,3,30),EXCO,ALPHA,SIGMA,
     $       EPSR,MODES,RHO,SKIP0(3)
      COMMON/ONE/RMAX,RSUM,NEWD,NEWHGT,NEWHGR,NEWP
      COMMON/IDENT/SKIP1(20),FRQ,TLT,RLT,RCOMP,SKIP2(6),POWER
      COMMON/DIMEN/SKIP3(18),NPRINT
      COMMON NOMODE(30)
C
      COMPLEX*16 STP,TP,AV1,AV2,AVT,AVR,EX,EX1,EX2,EXR,HG,HG1,HG2,HGT,
     $            HGR,SAV,SEX,SHG,SUMA,SUME,SUM,TMP1,TMP2,TMP3,TMP4,
     $            MI/(0.D0,-1.D0)/
      COMPLEX* 8 SUMM
      REAL*8 LMO
      REAL*4 D,AMP,PHS,RSINT,RHO,SKIP1,FRQ,TLT,RLT,SKIP2,POWER,
     $       RMAX,RSUM,PHZ,REV,EXCO,SKIP3
      INTEGER TCOMP,RCOMP
      LOGICAL NOMODE
C
      DIMENSION SAV(  30),AVT(  30),           AV2(  30),
     $           SEX(3,30),           EX1(3,30),EX2(3,30),EXR(3,30),
     $           SHG(  30),HGT(3,30),HG1(  30),HG2(  30),HG (3,30),
     $           XMT(3,30),XAT(3,30),XAR(3,30),SUMA(30),T(3)
      DIMENSION S(30),LMO(3,30)
C
      DATA PI/3.14159265D0/,TWOPI/6.28318531D0/,RTD/57.29578D0/
      DATA RHOINC/.02D0/
C
      IF(J .GT. 1) GO TO 1
      FREQ=FRQ
      TALT=TLT
      RALT=RLT
      SUMO=EXCO*SQRT(POWER)
      WAVEN=20.958445E0*FREQ
      PHZ=0.
      REV=0.
C...FOR PRINT
      ACONST=-8.686D0*WAVEN
C...REFERENCE EXCITATION TO REFLHT=70
      TMP4=DCMPLX(0.D0,-.035D0*WAVEN)
C
C...CHECK IF RECEIVER IS AT TRANSMITTER
1     IF(D .GT. 0.) GO TO 9
      SUMM=SUMO*80.D0
      AMP=20.D0*DLOG10(SUMO*80.D0)
      PHS=0.
      RETURN
C
9     DST=D
      RST=RSINT
      IF(RSUM .GT. 0.) GO TO 29
C...FIRST POINT ON PATH
      RHO0=0.D0
      RHOSUM=0.D0
      RHOMAX=RMAX
```

```
      REWIND 3
      REWIND 4
C
C...TRANSMITTER DATA
      READ(3) STP,TP,AV1,EX,SIGMA,EPSR,RHO,MODES,NOMODE
      RHO1=RHO
      IF(NEWD .EQ. 0 .AND. NEWHGT .EQ. 0) GO TO 10
C...TRANSMITTER HEIGHT GAINS
      CALL HTGAIN(1,FREQ,SIGMA,EPSR,ALPHA,MODES,TP,TALT,HGT)
10    IF(NEWD .EQ. 0 .AND. NEWHGR .EQ. 0) GO TO 11
C...RECEIVER HEIGHT GAINS
      CALL HTGAIN(1,FREQ,SIGMA,EPSR,ALPHA,MODES,TP,RALT,HG)
      WRITE(4) HG
      GO TO 12
11    READ(4) HG
C
C...SET UP MODE CONSTANTS
12    DO 14 M=1,MODES
      IF(NOMODE(M)) GO TO 14
      SUMA(M)=0.D0
      AVT(M)=AV1(M)
      HG1(M)=HG(RCOMP,M)
      DO 13 TCOMP=1,3
      EX1(TCOMP,M)=EX(TCOMP,RCOMP,M)
      XMT(TCOMP,M)=CDABS(EX1(TCOMP,M))
      X=EX1(TCOMP,M)
      Y=EX1(TCOMP,M)*MI
      XAT(TCOMP,M)=DATAN2(Y,X)
13    XAR(TCOMP,M)=XAT(TCOMP,M)
14    CONTINUE
      IF(NEWP .EQ. 0 .OR. NPRINT .EQ. 0) GO TO 20
C
C...PRINT TABLE OF MODE CONSTANTS AT TRANSMITTER
      PRINT 1040,RHO1
      DO 16 M=1,MODES
      IF(NOMODE(M)) GO TO 15
      STPR=STP(M)
      STPI=STP(M)*MI
      ATTEN=ACONST*STPI
      VOVERC=1.D0/STPR
      TMP1=TMP4*EX1(1,M)*HGT(1,M)*HG1(M)
      X=TMP1
      Y=TMP1*MI
      AMP1=10.D0*DLOG10(X*X+Y*Y)
      ANG1=DATAN2(Y,X)
      TMP2=TMP4*EX1(2,M)*HGT(2,M)*HG1(M)
      X=TMP2
      Y=TMP2*MI
      AMP2=10.D0*DLOG10(X*X+Y*Y)
      ANG2=DATAN2(Y,X)
      TMP3=TMP4*EX1(3,M)*HGT(3,M)*HG1(M)
      X=TMP3
      Y=TMP3*MI
      AMP3=10.D0*DLOG10(X*X+Y*Y)
      ANG3=DATAN2(Y,X)
      S(M)=0.D0
      LMO(1,M) = AMP1
```

```
      LMO(2,M) = AMP2
      LMO(3,M) = AMP3
      PRINT 1041,M,ATTEN,VOVERC,AMP1,ANG1,AMP2,ANG2,AMP3,ANG3,
     $            AMP1,AMP2,AMP3
      GO TO 16
15    PRINT 1041,M
16    CONTINUE
C
C...RECEIVER POINT DATA
20    READ(3) STP,TP,AV2,EX,SIGMA,EPSR,RHO,MODES,NOMODE
      RHO2=RHO
      IF(NEWD .EQ. 0 .AND. NEWHGR .EQ. 0) GO TO 21
      CALL HTGAIN(1,FREQ,SIGMA,EPSR,ALPHA,MODES,TP,RALT,HG)
      WRITE(4) HG
      GO TO 22
21    READ(4) HG
22    DO 23 M=1,MODES
      HG2(M)=HG(RCOMP,M)
      DO 23 TCOMP=1,3
      EX2(TCOMP,M)=EX(TCOMP,RCOMP,M)
23    CONTINUE
      IF(NEWP .EQ. 0 .OR. NPRINT .EQ. 0) GO TO 25
C
C...PRINT TABLE OF MODE CONSTANTS AT RECEIVER
      PRINT 1040,RHO2
      DRHO=8.686D0*(RHO2-RHO1)
      DO 24 M=1,MODES
      IF(NOMODE(M)) GO TO 240
      STPR=STP(M)
      STPI=STP(M)*MI
      ATTEN=ACONST*STPI
      VOVERC=1.D0/STPR
      TMP1=TMP4*EX2(1,M)*HGT(1,M)*HG2(M)
      X=TMP1
      Y=TMP1*MI
      AMP1=10.D0*DLOG10(X*X+Y*Y)
      ANG1=DATAN2(Y,X)
      TMP2=TMP4*EX2(2,M)*HGT(2,M)*HG2(M)
      X=TMP2
      Y=TMP2*MI
      AMP2=10.D0*DLOG10(X*X+Y*Y)
      ANG2=DATAN2(Y,X)
      TMP3=TMP4*EX2(3,M)*HGT(3,M)*HG2(M)
      X=TMP3
      Y=TMP3*MI
      AMP3=10.D0*DLOG10(X*X+Y*Y)
      ANG3=DATAN2(Y,X)
      DAV=AV1(M)+AV2(M)
      S(M)=S(M)+DRHO*DAV
C
C...RELATIVE EXCITATION FACTORS AT BEGINNING OF SEGMENT
      REL1=.5D0*(LMO(1,M)+AMP1+S(M))
      REL2=.5D0*(LMO(2,M)+AMP2+S(M))
      REL3=.5D0*(LMO(3,M)+AMP3+S(M))
      PRINT 1041,M,ATTEN,VOVERC,AMP1,ANG1,AMP2,ANG2,AMP3,ANG3,
     $            REL1,REL2,REL3
      GO TO 24
```

```
240   PRINT 1041,M
C
C...SET UP LINEAR INTERPOLATION ARRAYS
24    CONTINUE
25    DRHO=RHO2-RHO1
      IF(DRHO .EQ. 0.D0) GO TO 27
      DO 260 M=1,MODES
      IF(NOMODE(M)) GO TO 260
      SAV(M)=(AV2(M)-AV1(M))/DRHO
      SHG(M)=(HG2(M)-HG1(M))/DRHO
      DO 26 TCOMP=1,3
26    SEX(TCOMP,M)=(EX2(TCOMP,M)-EX1(TCOMP,M))/DRHO
260   CONTINUE
      IF(RHOSUM .EQ. DST) GO TO 99
      GO TO 30
C
C...DUPLICATE RHO DATA, ABRUPT CHANGE IN PATH ASSUMED
27    DO 28 M=1,MODES
      AV1(M)=AV2(M)
      HG1(M)=HG2(M)
      DO 28 TCOMP=1,3
      EX1(TCOMP,M)=EX2(TCOMP,M)
28    CONTINUE
      GO TO 20
C
29    IF(RHOSUM .EQ. DST) GO TO 40
30    RHOSUM=RHOSUM+RHOINC
      IF(RHOSUM .GT. DST) RHOSUM=DST
      IF(RHOSUM .GT. RHOMAX) GO TO 31
      IF(RHOSUM .GT. RHO2) RHOSUM=RHO2
31    DRHO=RHOSUM-RHO0
      DRHO1=RHOSUM-RHO1
      DRHO2=DRHO1-.5D0*DRHO
C
C...LOOP OVER MODES AT RECEIVER
      DO 34 M=1,MODES
      IF(NOMODE(M)) GO TO 34
C...INTEGRAL OVER S
      SUMA(M)=SUMA(M)+(AV1(M)+SAV(M)*DRHO2)*DRHO
C...LOOP OVER TRANSMITTED COMPONENTS - FOR PHASE CONTINUITY
      DO 33 TCOMP=1,3
      EXR(TCOMP,M)=EX1(TCOMP,M)+SEX(TCOMP,M)*DRHO1
      PHI1=XAR(TCOMP,M)
      X=EXR(TCOMP,M)
      Y=EXR(TCOMP,M)*MI
      PHI2=DATAN2(Y,X)
      IF(PHI2-PHI1 .LE. PI) GO TO 32
      PHI2=PHI2-TWOPI
      GO TO 33
32    IF(PHI1-PHI2 .LE. PI) GO TO 33
      PHI2=PHI2+TWOPI
33    XAR(TCOMP,M)=PHI2
34    CONTINUE
      RHO0=RHOSUM
C
      IF(RHOSUM .LT. DST) GO TO 50
C
```

```
C...MODE PARAMETERS AT RECEIVER DISTANCE
      STERM=SUMO/DSQRT(DABS(DSIN(DST/6.366D0)))
      DO 39 M=1,MODES
      IF(NOMODE(M)) GO TO 39
      HGR=HG1(M)+SHG(M)*DRHO1
      DO 38 TCOMP=1,3
      XMR=CDABS(EXR(TCOMP,M))
      EXM=DSQRT(XMT(TCOMP,M)*XMR)
      EXA=.5D0*(XAT(TCOMP,M)+XAR(TCOMP,M))
38    EXR(TCOMP,M)=EXM*DCMPLX(DCOS(EXA),DSIN(EXA))*HGT(TCOMP,M)*HGR
39    CONTINUE
C
C...MODE SUMMATION
40    SUM=0.D0
      DO 42 M=1,MODES
      IF(NOMODE(M)) GO TO 42
      SUME=0.D0
      DO 41 TCOMP=1,3
41    SUME=SUME+EXR(TCOMP,M)*T(TCOMP)
      SUM=SUM+CDEXP(SUMA(M)-RST*AVT(M))*SUME
42    CONTINUE
C
C...STORE MODE SUM PARAMETERS
      SUM=SUM*STERM
      SUMM=SUM
      X=SUM
      Y=SUM*MI
      AMP=10.D0*DLOG10(X*X+Y*Y)
      PHS=DATAN2(Y,X)*RTD
      IF(PHS-PHZ .LE. 180.) GO TO 43
      REV=REV-360.
      GO TO 44
43    IF(PHZ-PHS .LE. 180.) GO TO 44
      REV=REV+360.
44    PHZ=PHS
      PHS=PHS+REV
      IF(RHOSUM .EQ. RHO2 .AND. RHO2 .NE. RHOMAX) GO TO 51
      GO TO 99
C
50    IF(RHOSUM .LT. RHO2 .OR. RHO2 .EQ. RHOMAX) GO TO 30
51    RHO1=RHO2
C...GO TO REASSIGN MODE CONSTANTS
      GO TO 27
C
99    RSUM=RHOSUM
      RETURN
C
1040  FORMAT('ORHO = ',F6.3,'  MODE  ATTEN   V/C',9X,'VERTICAL',9X,
     $        'BROADSIDE',8X,'END FIRE',11X,'V',10X,'B',10X,'E')
1041  FORMAT(15X,I3,F8.3,F9.5,3(F10.3,F7.3),3(4X,F7.2))
      END
```

```
      SUBROUTINE POUT1(JJ,JJMAX)
      COMMON/DIMEN/SIZEX,SIZEY,AMPMAX,AMPMIN,AMPINC,PHSMAX,PHSMIN,
     $        PHSINC,XMAX,XMIN,XINC,SKIP1(3),
     $        NRCURV,NAPLOT,NPPLOT,NPDIFF,NPRINT
      COMMON/IDENT/ID(20),FREQ,TALT,RALT,ICOMP,ZYX,IOPT,THET,INCL,
     $        DST,RADIUS,POWER
      COMMON/OUTPUT/XY(501),OUT1(501),OUT2(501),NRPTS,NRCRVS,
     $        NRPLTS,DT(4)
      COMMON PHI1(501),UP(501),XL(2),YL(2),UL(2)
      LOGICAL UP,UL
      REAL INCL
C
      IR=-1
      KK=MOD(JJ,NRCURV)
      IF(KK .EQ. 0) KK=NRCURV
      IF(JJ .GT. 1) GO TO 10
      NFRAME=1
      OFFSET=AMAX1(10.5,SIZEX+2.5)
      DO 1 I=1,NRPTS
    1 PHI1(I)=OUT2(I)
C
   10 IF(NPRINT .EQ. 0) GO TO 20
      PRINT 1001,ZYX,INCL,THET,TALT,RALT
      NL=NRPTS/4+1
      DO 19 I1=1,NL
   19 PRINT 1011,(XY(I),OUT1(I),OUT2(I),I=I1,NRPTS,NL)
C
   20 IF(NAPLOT .EQ. 0) GO TO 30
      IR=IR+1
      NPLOT=1
      AMAX=AMPMAX
      AMIN=AMPMIN
      AINC=AMPINC
      DO 29 I=1,NRPTS
      UP(I)=.FALSE.
      IF(OUT1(I) .LE. AMAX) GO TO 27
      OUT1(I)=AMAX
      GO TO 28
   27 IF(OUT1(I) .GE. AMIN) GO TO 29
      OUT1(I)=AMIN
   28 UP(I)=.TRUE.
   29 CONTINUE
      YMAX=AMAX
      YMIN=AMIN
      YINC=AINC
      GO TO 100
C
   30 IF(NPPLOT .EQ. 0) GO TO 40
      IR=IR+1
      IF(IR .NE. 0) CALL PLOT(OFFSET,0.,-3)
      NPLOT=2
      FK=0.
      DO 39 I=1,NRPTS
      OUT1(I)=OUT2(I)+FK
      UP(I)=.FALSE.
   35 IF(OUT1(I) .LT. PHSMIN) GO TO 36
```

```
      IF(OUT1(I) .GT. PHSMAX) GO TO 37
      GO TO 39
36    FK=FK-PHSMIN
      OUT1(I)=OUT1(I)-PHSMIN
      GO TO 38
37    FK=FK-PHSMAX
      OUT1(I)=OUT1(I)-PHSMAX
38    UP(I)=.TRUE.
      GO TO 35
39    CONTINUE
      YMAX=PHSMAX
      YMIN=PHSMIN
      YINC=PHSINC
      GO TO 100
C
40    IF(NPDIFF .EQ. 0) GO TO 50
      IR=IR+1
      IF(IR .NE. 0) CALL PLOT(OFFSET,0.,-3)
      NPLOT=3
      FK=0.
      DO 49 I=1,NRPTS
      OUT1(I)=OUT2(I)-FHI1(I)+FK
      UP(I)=.FALSE.
45    IF(OUT1(I) .LT. PHSMIN) GO TO 46
      IF(OUT1(I) .GT. PHSMAX) GO TO 47
      GO TO 49
46    FK=FK-PHSMIN
      OUT1(I)=OUT1(I)-PHSMIN
      GO TO 48
47    FK=FK-PHSMAX
      OUT1(I)=OUT1(I)-PHSMAX
48    UP(I)=.TRUE.
      GO TO 45
49    CONTINUE
      YMAX=PHSMAX
      YMIN=PHSMIN
      YINC=PHSINC
      GO TO 100
C
50    IF(KK .EQ. NRCURV .OR. JJ .EQ. JJMAX) GO TO 51
      IF(IR .EQ. 0) GO TO 99
      CALL PLOT(-IR*OFFSET,0.,-3)
      GO TO 99
51    CALL PLOT(0.,0.,-4)
      NFRAME=1
99    RETURN
C
100   IF(KK .NE. 1) GO TO 130
      IF(NFRAME .EQ. 1) CALL PLOT(1.5,2.0,-3)
      NFRAME=0
      NRPLTS=NRPLTS+1
      XP=0.
      YP=-.4
      CALL SYMBOL(XP,YP,.1,4HFLD4,0.,4)
      XP=XP+0.5
      CALL NUMBER(XP,YP,.1,FLOAT(NRPLTS),0.,-1)
      XP=XP+1.0
```

```
      CALL SYMBOL(XP,YP,.1,DT,0.,16)
      XP=0.
      YP=YP-.15
      IF(NPLOT-2) 101,102,103
101   CALL SYMBOL(XP,YP,.1,9HAMPLITUDE,0.,9)
      GO TO 104
102   CALL SYMBOL(XP,YP,.1,14HRELATIVE PHASE,0.,14)
      GO TO 104
103   CALL SYMBOL(XP,YP,.1,12HPHASE-PHASE1,0.,12)
104   XP=0.
      YP=YP-.15
      CALL SYMBOL(XP,YP,.1,ZYX,0.,1)
      XP=XP+0.2
      CALL SYMBOL(XP,YP,.1,9HCOMPONENT,0.,9)
      XP=XP+1.5
      CALL SYMBOL(XP,YP,.1,6HFREQ =,0.,6)
      XP=XP+0.7
      CALL NUMBER(XP,YP,.1,FREQ,0.,3)
      XP=XP+1.0
      CALL SYMBOL(XP,YP,.1,7HPOWER =,0.,7)
      XP=XP+0.8
      CALL NUMBER(XP,YP,.1,POWER,0.,1)
      XP=0.
      YP=YP-.15
      CALL SYMBOL(XP,YP,.1,6HTALT =,0.,6)
      XP=XP+0.7
      CALL NUMBER(XP,YP,.1,TALT,0.,1)
      XP=XP+1.0
      CALL SYMBOL(XP,YP,.1,6HRALT =,0.,6)
      XP=XP+0.7
      CALL NUMBER(XP,YP,.1,RALT,0.,1)
      XP=XP+1.0
      IF(IOPT .EQ. 1) GO TO 118
      XP=0.
      YP=YP-.15
      CALL SYMBOL(XP,YP,.1,6HINCL =,0.,6)
      XP=XP+0.7
      CALL NUMBER(XP,YP,.1,INCL,0.,3)
      XP=XP+1.0
      CALL SYMBOL(XP,YP,.1,7HTHETA =,0.,7)
      XP=XP+0.8
      CALL NUMBER(XP,YP,.1,THET,0.,3)
      XP=XP+1.0
      GO TO 119
118   XP=0.
      YP=YP-.15
      CALL SYMBOL(XP,YP,.1,ID,0.,80)
119   CALL BORDER(SIZEX,XMIN,XMAX,XINC,1,SIZEY,YMIN,YMAX,YINC,1)
      YPO=YP
C
130   NRCRVS=NRCRVS+1
      XP=0.
      YP=YPO-.15*KK
      XL(1)=-1.1
      XL(2)=-0.1
      YL(1)=YP
      YL(2)=YP
```

```
      UL(1)=.FALSE.
      UL(2)=.FALSE.
      CALL CURVE(XL,YL,UL,2,0.,0.,1.,1.,KK)
      IF(IOPT .EQ. 4) GO TO 134
      CALL SYMBOL(XP,YP,.1,6HINCL =,0.,6)
      XP=XP+0.7
      CALL NUMBER(XP,YP,.1,INCL,0.,3)
      XP=XP+1.0
      CALL SYMBOL(XP,YP,.1,7HTHETA =,0.,7)
      XP=XP+0.7
      CALL NUMBER(XP,YP,.1,THET,0.,3)
      GO TO 151
134   CALL SYMBOL(XP,YP,.1,ID,0.,80)
C
C...DRAW CURVES
151   CALL CURVE(XY,OUT1,UP,NRPTS,XMIN,YMIN,(XMAX-XMIN)/SIZEX,
     $     (YMAX-YMIN)/SIZEY,KK)
199   IF(NPLOT-2) 30,40,50
C
1001  FORMAT('0',A1,' COMP  INCL = ',F7.3,'  THETA = ',F8.3,' TALT = ',
     $       F5.1,' RALT = ',F5.1/4('  DIST   AMPLITUDE  PHASE',7X))
1011  FORMAT(4(F7.3,2F10.4,5X))
      END
```

```
      SUBROUTINE POUT2(JJ,II)
      COMMON/IDENT/ID(20),FREQ,TALT,RALT,ICOMP,ZYX,IOPT,THTANG,INCANG,
     $        DIST,RADIUS,POWER
      COMMON/DIMEN/SIZEX,SKIP2(10),TMAX,TMIN,SKIP3(5),NPRINT
      COMMON/OUTPUT/T(501),AMP(501),PHS(501),NRPTS,NRCRVS,NRPLTS,DT(4)
      COMMON UP(501)
      LOGICAL UP
      CHARACTER ZYX
      REAL INCANG
C
      IF(II .GT. 1 .OR. JJ .GT. 1) GO TO 9
      NRPLTS=NRPLTS+1
      YP=9.6
      CALL SYMBOL(0.0,YP,.1,4HFLD4,0.,4)
      CALL NUMBER(0.5,YP,.1,FLOAT(NRPLTS),0.,-1)
      CALL SYMBOL(1.0,YP,.1,DT,0.,16)
      YP=YP-.2
      CALL SYMBOL(0.0,YP,.1,ID,0.,80)
      YP=YP-.2
      CALL SYMBOL(0.0,YP,.1,ZYX,0.,1)
      CALL SYMBOL(0.2,YP,.1,9HCOMPONENT,0.,9)
      YP=YP-.2
      CALL SYMBOL(0.0,YP,.1,23HFREQ =          POWER = ,0.,23)
      CALL NUMBER(0.7,YP,.1,FREQ,0.,3)
      CALL NUMBER(2.3,YP,.1,POWER,0.,1)
      YP=YP-.2
      CALL SYMBOL(0.0,YP,.1,23HT ALT =         R ALT = ,0.,23)
      CALL NUMBER(0.8,YP,.1,TALT,0.,1)
      CALL NUMBER(2.3,YP,.1,RALT,0.,1)
      YP=YP-.2
      CALL SYMBOL(0.0,YP,.1,7HINCL = ,0.,7)
      CALL NUMBER(0.7,YP,.1,INCANG,0.,3)
      YP=YP-.2
      CALL SYMBOL(0.0,YP,.1,9HRADIUS = ,0.,9)
      CALL NUMBER(0.9,YP,.1,RADIUS,0.,4)
      YP=YP-.2
C
    9 IF(JJ .GT. 1) GO TO 33
C
      IF(NPRINT .EQ. 0) GO TO 20
      PRINT 1000,ZYX,DIST,INCANG
      NL=NRPTS/4+1
      DO 19 I1=1,NL
   19 PRINT 1011,(T(I),AMP(I),PHS(I),I=I1,NRPTS,NL)
C
   20 CALL SYMBOL(0.00,-.40,.10,7HDIST = ,0.,7)
      CALL NUMBER(0.70,-.40,.10,DIST,0.,3)
      CALL BORDER(SIZEX,TMIN,TMAX,90.,1,4.,-360., 360.,90.,1)
      CALL SYMBOL(-.2,1.7,.1,7HDEGREES,90.,7)
C
   33 NRCRVS=NRCRVS+1
      FK=0.
      DO 38 J=1,NRPTS
      YP=PHS(J)+FK
      UP(J)=.FALSE.
   34 IF(YP .LT. -360.) GO TO 35
```

```
      IF(YP .GT.  360.) GO TO 36
      GO TO 38
   35 FK=FK+360.
      YP=YP+360.
      GO TO 37
   36 FK=FK-360.
      YP=YP-360.
   37 UP(J)=.TRUE.
      GO TO 34
   38 PHS(J)=YP
      CALL CURVE(T,PHS,UP,NRPTS,TMIN,-360.,(TMAX-TMIN)/SIZEX,180.,JJ)
C
      NRCRVS=NRCRVS+1
      CALL PLOT(0.,4.3,-3)
      IF(JJ .GT. 1) GO TO 44
      AMAX=-100.
      AMIN= 100.
      DO 40 J=1,NRPTS
      AMPJ=AMP(J)
      IF(AMIN .GT. AMPJ) AMIN=AMPJ
      IF(AMAX .LT. AMPJ) AMAX=AMPJ
   40 CONTINUE
      AMAX=10.*AINT((.5*(AMAX+AMIN)+5.)/10.)+20.
      AMIN=AMAX-40.
      CALL BORDER(SIZEX,TMIN,TMAX,90.,1,4., AMIN, AMAX,10.,1)
      CALL SYMBOL(-.2,1.5,.1,10HDB/UV/M/KW,90.,10)
   44 DO 48 J=1,NRPTS
      AMPJ=AMP(J)
      UP(J)=.FALSE.
      IF(AMPJ .LE. AMAX) GO TO 46
      AMPJ=AMAX
      GO TO 47
   46 IF(AMPJ .GE. AMIN) GO TO 48
      AMPJ=AMIN
   47 UP(J)=.TRUE.
   48 AMP(J)=AMPJ
      CALL CURVE(T,AMP,UP,NRPTS,TMIN, AMIN,(TMAX-TMIN)/SIZEX, 10.,JJ)
C
      CALL PLOT(0.,-4.3,-3)
   99 RETURN
 1000 FORMAT('0',A1,' COMP  DIST = ',F7.3,' INCL = ',F7.3/
     $        4('  THETA  AMPLITUDE  PHASE',7X))
 1011 FORMAT(4(F7.3,2F10.4,5X))
      END
```

```
      SUBROUTINE CURVE(X,Y,UP,NRPTS,XMIN,YMIN,XINC,YINC,LINE)           CURVE000
C                                                                       CURVE000
C X,Y,UP MUST BE DIMENSIONED AT LEAST NRPTS                             CURVE000
C XMIN,YMIN ARE X,Y ORIGIN IN USER UNITS                                CURVE000
C XINC,YINC ARE X,Y SCALES IN USER UNITS PER INCH                       CURVE000
C                                                                       CURVE000
C LINE=1:  SOLID                                                        CURVE000
C      2:  LONG DASH                                                    CURVE000
C      3:  MEDIUM DASH                                                  CURVE000
C      4:  SHORT DASH                                                   CURVE000
C      5:  DOTTED                                                       CURVE000
C      6:  SHORT + LONG DASH                                            CURVE000
C      7:  SHORT + SHORT + LONG DASH                                    CURVE000
C                                                                       CURVE000
      LOGICAL UP,UP1,UP2                                                CURVE000
      DIMENSION IPEN(10),JDC(7),X(NRPTS),Y(NRPTS),UP(NRPTS)             CURVE000
      DATA IPEN/3,2,3,2,3,2,2,2,2,2/,JDC/18, 61, 56, 54, 52, 11, 36/    CURVE000
      DATA DELR/.1/                                                     CURVE000
C                                                                       CURVE000
      IF(NRPTS .LE. 1) GO TO 99                                         CURVE000
C                                                                       CURVE000
      IF(LINE) 1,2,3                                                    CURVE000
1     KK=MOD(LINE,7)+7                                                  CURVE000
      GO TO 4                                                           CURVE000
2     KK=0                                                              CURVE000
      GO TO 4                                                           CURVE000
3     KK=MOD(LINE,7)                                                    CURVE000
4     KK=KK+1                                                           CURVE000
      JO=JDC(KK)/10                                                     CURVE000
      JC=JDC(KK)-10*JO                                                  CURVE000
C                                                                       CURVE000
      J=1                                                               CURVE000
      IP=2                                                              CURVE000
      IF(KK .EQ. 6) IP=3                                                CURVE000
      DR=0.                                                             CURVE000
      RHO1=0.                                                           CURVE000
      RHO2=DELR                                                         CURVE000
      PX1=(X(1)-XMIN)/XINC                                              CURVE000
      PY1=(Y(1)-YMIN)/YINC                                              CURVE000
      UP1=UP(1)                                                         CURVE000
      IF(UP1) GO TO 10                                                  CURVE000
C                                                                       CURVE000
C GO TO FIRST POSITION WITH PEN UP                                      CURVE000
      CALL PLOT(PX1,PY1,3)                                              CURVE000
C                                                                       CURVE000
10    DO 40 I=2,NRPTS                                                   CURVE000
      PX2=(X(I)-XMIN)/XINC                                              CURVE000
      PY2=(Y(I)-YMIN)/YINC                                              CURVE000
      UP2=UP(I)                                                         CURVE000
      IF(UP2) GO TO 22                                                  CURVE000
      IF(UP1) GO TO 37                                                  CURVE000
      IF(KK .EQ. 2) GO TO 38                                            CURVE000
      DELX=PX2-PX1                                                      CURVE000
      DELY=PY2-PY1                                                      CURVE000
      RHO=SQRT(DELX**2+DELY**2)                                         CURVE000
      RHO1=RHO1+RHO                                                     CURVE000
```

```
      IF(RHO2 .GT. RHO1) GO TO 38                                  CURVE000
      DELX=DELX*DELR/RHO                                           CURVE000
      DELY=DELY*DELR/RHO                                           CURVE000
      DX 6=DELX*.1                                                 CURVE000
      DY 6=DELY*.1                                                 CURVE000
      IF(DR .EQ. 0.) GO TO 20                                      CURVE000
      DX=DELX*DR/DELR                                              CURVE000
      DY=DELY*DR/DELR                                              CURVE000
      PX1=PX1+DX                                                   CURVE000
      PY1=PY1+DY                                                   CURVE000
      GO TO 21                                                     CURVE000
   20 IF(RHO2 .GT. RHO1) GO TO 38                                  CURVE000
      PX1=PX1+DELX                                                 CURVE000
      PY1=PY1+DELY                                                 CURVE000
   21 CALL PLOT(PX1,PY1,IP)                                        CURVE000
      IF(KK .EQ. 6) CALL PLOT(PX1+DX6,PY1+DY6,2)                   CURVE000
      J=J+1                                                        CURVE000
      IP=IPEN(JO+MOD(J,JC))                                        CURVE000
      RHO2=RHO2+DELR                                               CURVE000
      GO TO 20                                                     CURVE000
   22 DR=0.                                                        CURVE000
      RHO1=0.                                                      CURVE000
      RHO2=DELR                                                    CURVE000
      GO TO 39                                                     CURVE000
C PEN HAS BEEN UP, PREPARE TO LOWER PEN                             CURVE000
   37 CALL PLOT(PX2,PY2,3)                                         CURVE000
      GO TO 39                                                     CURVE000
   38 CALL PLOT(PX2,PY2,IP)                                        CURVE000
      DR=RHO2-RHO1                                                 CURVE000
   39 PX1=PX2                                                      CURVE000
      PY1=PY2                                                      CURVE000
      UP1=UP2                                                      CURVE000
   40 CONTINUE                                                     CURVE000
   99 RETURN                                                       CURVE000
      END                                                          CURVE000
```

```
      SUBROUTINE BORDER(XLNG,XMIN,XMAX,XINC,NX,YLNG,YMIN,YMAX,YINC,NY)  BORDER00
      DIMENSION XINC(NX),YINC(NY)                                       BORDER00
      LOGICAL FY,FX                                                     BORDER00
      FX=.FALSE.                                                        BORDER00
      FY=.FALSE.                                                        BORDER00
      IF(NX .EQ. 1) FX=.TRUE.                                           BORDER00
      IF(NY .EQ. 1) FY=.TRUE.                                           BORDER00
      XT=XLNG-.1                                                        BORDER00
      YT=YLNG-.1                                                        BORDER00
      XSCALE=XLNG/(XMAX-XMIN)                                           BORDER00
      YSCALE=YLNG/(YMAX-YMIN)                                           BORDER00
      YM=ABS(YMIN)                                                      BORDER00
      YLN=-.4                                                           BORDER00
      IF(YM .GE. 10.) YLN=YLN-.1                                        BORDER00
      IF(YM .GE. 100.) YLN=YLN-.1                                       BORDER00
      IF(YM .GE. 1000.) YLN=YLN-.1                                      BORDER00
      IF(YMIN .LT. 0.) YLN=YLN-.1                                       BORDER00
      YM=ABS(YMAX)                                                      BORDER00
      YLM=-.4                                                           BORDER00
      IF(YM .GE. 10.) YLM=YLM-.1                                        BORDER00
      IF(YM .GE. 100.) YLM=YLM-.1                                       BORDER00
      IF(YM .GE. 1000.) YLM=YLM-.1                                      BORDER00
      IF(YMAX .LT. 0.) YLM=YLM-.1                                       BORDER00
      XM=ABS(XMAX)                                                      BORDER00
      XLM=-.3                                                           BORDER00
      IF(XM .GE. 10.) XLM=XLM-.1                                        BORDER00
      IF(XM .GE. 100.) XLM=XLM-.1                                       BORDER00
      IF(XM .GE. 1000.) XLM=XLM-.1                                      BORDER00
      IF(XMAX .LT. 0.) XLM=XLM-.1                                       BORDER00
      IF(FX) DX=XINC(1)                                                 BORDER00
      IF(FY) DY=YINC(1)                                                 BORDER00
      IY=1                                                              BORDER00
      YL=0.                                                             BORDER00
      CALL NUMBER(YLN,0.,.1,YMIN,0.,1)                                  BORDER00
      CALL PLOT(0.,0.,3)                                                BORDER00
      IF(FY) GO TO 110                                                  BORDER00
   10 YP=(YINC(IY)-YMIN)*YSCALE                                         BORDER00
      GO TO 111                                                         BORDER00
  110 YL=YL+DY                                                          BORDER00
      YP=YL*YSCALE                                                      BORDER00
  111 IF(YP .LT.  0.) GO TO 99                                          BORDER00
      IF(YP .GE. YLNG) GO TO 11                                         BORDER00
      CALL PLOT(0.,YP,2)                                                BORDER00
      CALL PLOT(.1,YP,2)                                                BORDER00
      CALL PLOT(0.,YP,2)                                                BORDER00
      IF(FY) GO TO 110                                                  BORDER00
      IY=IY+1                                                           BORDER00
      IF(IY .LE. NY) GO TO 10                                           BORDER00
   11 CALL PLOT(0.,YLNG,2)                                              BORDER00
      CALL NUMBER(YLM,YLNG-.1,.1,YMAX,0.,1)                             BORDER00
      CALL PLOT(0.,YLNG,3)                                              BORDER00
      IX=1                                                              BORDER00
      XL=0.                                                             BORDER00
      IF(FX) GO TO 112                                                  BORDER00
   12 XP=(XINC(IX)-XMIN)*XSCALE                                         BORDER00
      GO TC 120                                                         BORDER00
```

```
112   XL=XL+DX                                                      BORDER00
      XP=XL*XSCALE                                                  BORDER00
120   IF(XP .LT.   0.) GO TO 99                                     BORDER00
      IF(XP .GE. XLNG) GO TO 13                                     BORDER00
      CALL PLOT(XP,YLNG,2)                                          BORDER00
      CALL PLOT(XP,YT,2)                                            BORDER00
      CALL PLOT(XP,YLNG,2)                                          BORDER00
      IF(FX) GO TO 112                                              BORDER00
      IX=IX+1                                                       BORDER00
      IF(IX .LE. NX) GO TO 12                                       BORDER00
13    CALL PLOT(XLNG,YLNG,2)                                        BORDER00
      IF(FY) GO TO 130                                              BORDER00
113   IY=IY-1                                                       BORDER00
      IF(IY .LE. 0) GO TO 15                                        BORDER00
      YP=(YINC(IY)-YMIN)*YSCALE                                     BORDER00
      GO TO 14                                                      BORDER00
130   YL=YL-DY                                                      BORDER00
      YP=YL*YSCALE                                                  BORDER00
      IF(YP .LE. 0.) GO TO 15                                       BORDER00
14    CALL PLOT(XLNG,YP,2)                                          BORDER00
      CALL PLOT(XT,YP,2)                                            BORDER00
      CALL PLOT(XLNG,YP,2)                                          BORDER00
      IF(FY) GO TO 130                                              BORDER00
      GO TO 113                                                     BORDER00
15    CALL PLOT(XLNG,0.,2)                                          BORDER00
      CALL NUMBER(XLNG+XLM,-.2,.1,XMAX,0.,1)                        BORDER00
      CALL PLOT(XLNG,0.,3)                                          BORDER00
      IF(FX) GO TO 150                                              BORDER00
115   IX=IX-1                                                       BORDER00
      IF(IX .LE. 0) GO TO 17                                        BORDER00
      XP=(XINC(IX)-XMIN)*XSCALE                                     BORDER00
      GO TO 16                                                      BORDER00
150   XL=XL-DX                                                      BORDER00
      XP=XL*XSCALE                                                  BORDER00
      IF(XP .LE. 0.) GO TO 17                                       BORDER00
16    CALL PLOT(XP,0.,2)                                            BORDER00
      CALL PLOT(XP,.1,2)                                            BORDER00
      CALL PLOT(XP,0.,2)                                            BORDER00
      IF(FX) GO TO 150                                              BORDER00
      GO TO 115                                                     BORDER00
17    CALL PLOT(0.,0.,2)                                            BORDER00
      CALL NUMBER(0.,-.2,.1,XMIN,0.,1)                              BORDER00
      RETURN                                                        BORDER00
99    PRINT 100,XLNG,XMIN,XMAX,XINC(1),NX,YLNG,YMIN,YMAX,YINC(1),NY BORDER00
100   FORMAT('0***  ERROR IN BORDER:  XLNG, XMIN, XMAX, XINC(1), NX =', BORDER00
     $       1P4E15.5,I5/24X,'YLNG, YMIN, YMAX, YINC(1), NY =',1P4E15.5,BORDER00
     $       I5/'0***')                                             BORDER00
      CALL PLOT(0.,0.,999)                                          BORDER00
      STOP                                                          BORDER00
      END                                                           BORDER00
```

```
      SUBROUTINE HTGAIN(IOPT,FREQ,SIGMA,EPSR,ALPHA,NRMODE,TP,Z,HG)      HTGAIN00
      IMPLICIT REAL*8 (A-H,O-Z)                                         HTGAIN00
      COMPLEX*16 TP(1),HG(3,1),HGO/(0.D0,1.4574954400)/,                HTGAIN00
     $           S,C,SSQ,CSQ,NGSQ,SQROOT,RATIO,A1,A2,A3,A4,             HTGAIN00
     $           PO,H10,H20,H1PRMO,H2PRMO,PZ,H1Z,H2Z,H1PRMZ,H2PRMZ,EXPZ,HTGAIN00
     $           I/(0.D0,1.D0)/,MI/(0.D0,-1.D0)/,ONE/(1.D0,0.D0)/       HTGAIN00
      REAL*8 K,KA13,KA23                                                HTGAIN00
      DATA DTR/1.745329252D-02/                                         HTGAIN00
C                                                                       HTGAIN00
      OMEGA=6.2831853072D03*FREQ                                        HTGAIN00
      NGSQ=DCMPLX(EPSR,-SIGMA/(8.85434D-12*OMEGA))                      HTGAIN00
      K=2.09584260D-02*FREQ                                             HTGAIN00
      IF(ALPHA .EQ. 0.D0) GO TO 5                                       HTGAIN00
      AK=ALPHA/K                                                        HTGAIN00
      AK13=DEXP(DLOG(AK)/3.D0)                                          HTGAIN00
      AK23=AK13**2                                                      HTGAIN00
      KA13=1.D0/AK13                                                    HTGAIN00
      KA23=KA13**2                                                      HTGAIN00
      P1=KA23-ALPHA*Z                                                   HTGAIN00
      EXPZ=DEXP(.5D0*ALPHA*Z)                                           HTGAIN00
    5 DO 20 M=1,NRMODE                                                  HTGAIN00
      S=CDSIN(TP(M)*DTR)                                                HTGAIN00
      SSQ=S*S                                                           HTGAIN00
      CSQ=ONE-SSQ                                                       HTGAIN00
      SQROOT=CDSQRT(NGSQ-SSQ)                                           HTGAIN00
      TEST=TP(M)*I                                                      HTGAIN00
      IF(TEST .GT. 10.D0 .OR. ALPHA .EQ. 0.D0) GO TO 10                 HTGAIN00
      PO=KA23*CSQ                                                       HTGAIN00
      CALL MDHNKL(PO,H10,H20,H1PRMO,H2PRMO,TP(M),'HG 1')                HTGAIN00
      PZ=PO+P1                                                          HTGAIN00
      CALL MDHNKL(PZ,H1Z,H2Z,H1PRMZ,H2PRMZ,TP(M),'HG 2')                HTGAIN00
      A1=H10   *H2Z   -H1Z   *H20                                       HTGAIN00
      A2=H1PRMO*H2Z   -H1Z   *H2PRMO                                    HTGAIN00
      A3=H10   *H2PRMZ-H1PRMZ*H20                                       HTGAIN00
      A4=H1PRMO*H2PRMZ-H1PRMZ*H2PRMO                                    HTGAIN00
      RATIO=SQROOT/NGSQ                                                 HTGAIN00
      C=.5D0*AK23+KA13*MI*RATIO                                         HTGAIN00
      HG(1,M)=EXPZ*(C*A1+A2)                                            HTGAIN00
      HG(2,M)=KA13*MI*SQROOT*A1+A2                                      HTGAIN00
      HG(3,M)=.5D0*AK*MI*HG(1,M)+AK13*MI*EXPZ*(C*A3+A4)                 HTGAIN00
      IF(IOPT .EQ. 1) GO TO 20                                          HTGAIN00
      HG(1,M)=HG(1,M)/HGO                                               HTGAIN00
      HG(2,M)=HG(2,M)/HGO                                               HTGAIN00
      HG(3,M)=HG(3,M)/(RATIO*HGO)                                       HTGAIN00
      GO TO 20                                                          HTGAIN00
   10 C=CDSQRT(CSQ)                                                     HTGAIN00
      EXPZ=CDEXP(DCMPLX(0.D0,K*Z)*C)                                    HTGAIN00
      A1=(NGSQ*C-SQROOT)/(NGSQ*C+SQROOT)                                HTGAIN00
      A2=(C-SQROOT)/(C+SQROOT)                                          HTGAIN00
      HG(1,M)=EXPZ+A1/EXPZ                                              HTGAIN00
      HG(2,M)=EXPZ+A2/EXPZ                                              HTGAIN00
      HG(3,M)=(EXPZ-A1/EXPZ)*C                                          HTGAIN00
      IF(IOPT .EQ. 1) GO TO 20                                          HTGAIN00
      HG(1,M)=HG(1,M)/(ONE+A1)                                          HTGAIN00
      HG(2,M)=HG(2,M)/(ONE+A2)                                          HTGAIN00
      HG(3,M)=HG(3,M)/((ONE-A1)*C)                                      HTGAIN00
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   20 CONTINUE                                                  HTGAIN00
      RETURN                                                    HTGAIN00
      END                                                       HTGAIN00
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      SUBROUTINE MDHNKL (Z,H1,H2,H1PRME,H2PRME,THETA,IDBG)              MDHNKL00
      IMPLICIT COMPLEX*16 (A-H,O-Z)                                     MDHNKL00
      COMPLEX*16 I,MI,MPOWER,MTERM                                      MDHNKL00
      REAL*8 A,B,C,D,CAP,PART1,PART2,ZMAG                               MDHNKL00
      DIMENSION A(30), B(30), C(30), D(30), CAP(30), PART1(2), PART2(2) MDHNKL00
      EQUIVALENCE (PART1,TERM4), (PART2,SUM4)                           MDHNKL00
C                                                                       MDHNKL00
      DATA A    /  9.3043671692922944819D-01,  3.1014557230974314911D+01,MDHNKL00
     $             2.0676371487316209897D+02,  5.7434365242545027449D+02,MDHNKL00
     $             8.7021765519007617234D+02,  8.2877871922864397320D+02,MDHNKL00
     $             5.4168543740434246542D+02,  2.5794544638302022111D+02,MDHNKL00
     $             9.3458495066311674231D+01,  2.6626351870744066662D+01,MDHNKL00
     $             6.1210004300561072794D+00,  1.1592803844803233472D+00,MDHNKL00
     $             1.8401275944132116616D-01,  2.4833030953741048003D-02,MDHNKL00
     $             2.8842080097260218300D-03,  2.9133414239656786138D-04,MDHNKL00
     $             2.5827494893312753646D-05,  2.0256858739853140063D-06,MDHNKL00
     $             1.4155736366074870734D-07,  8.8695090013000443124D-09,MDHNKL00
     $             5.0110220346327933889D-10,  2.5658074934115668552D-11,MDHNKL00
     $             1.1961806496091228666D-12,  5.0988092481207283185D-14,MDHNKL00
     $             1.9948392989517716388D-15,  7.1886100863126905797D-17,MDHNKL00
     $             2.3938095525516785112D-18,  7.3883010881224645255D-20,MDHNKL00
     $             2.1194208514407528762D-21,  5.6653858632471341093D-23/MDHNKL00
      DATA B    /  6.7829872514427588456D-01,  1.1304978752404598033D+01,MDHNKL00
     $             5.3833232154307609704D+01,  1.1962940478735024370D+02,MDHNKL00
     $             1.5337103177865415841D+02,  1.2780919314887846509D+02,MDHNKL00
     $             7.4742218215718400631D+01,  3.2355938621523117060D+01,MDHNKL00
     $             1.0785312873841039006D+01,  2.8532573740320209005D+00,MDHNKL00
     $             6.1360373635097223595D-01,  1.0937678009821251966D-01,MDHNKL00
     $             1.6422939954686564465D-02,  2.1055051223957133911D-03,MDHNKL00
     $             2.3316778764072130571D-04,  2.2528288660939256561D-05,MDHNKL00
     $             1.9156708045016374595D-06,  1.4446989475879618839D-07,MDHNKL00
     $             9.7286124416697769730D-09,  5.8854279743918795891D-10,MDHNKL00
     $             3.2160808603234314644D-11,  1.5952782045255116351D-12,MDHNKL00
     $             7.2151886229105003778D-14,  2.9876557444763976717D-15,MDHNKL00
     $             1.1368553061173507104D-16,  3.9889659863766691603D-18,MDHNKL00
     $             1.2946984700995355913D-19,  3.8985199340546088228D-21,MDHNKL00
     $             1.0920223904914870636D-22,  2.8527230681595795812D-24/MDHNKL00
      DATA C    /  4.6521835846461472410D-01,  6.2029114461948629822D+00,MDHNKL00
     $             2.5845464359145252382D+01,  5.2213059311404570392D+01,MDHNKL00
     $             6.2158403942148298012D+01,  4.8751689366390821897D+01,MDHNKL00
     $             2.7084271870217123228D+01,  1.1215019407957400903D+01,MDHNKL00
     $             3.5945575025504490022D+00,  9.1815006450841609147D-01,MDHNKL00
     $             1.9128126343925335199D-01,  3.3122296699437809740D-02,MDHNKL00
     $             4.8424410379295043444D-03,  6.0568368204246458321D-04,MDHNKL00
     $             6.5550182039227768583D-05,  6.1985987743950608612D-06,MDHNKL00
     $             5.1654989786625507119D-07,  3.8220488188402150986D-08,MDHNKL00
     $             2.5276100653705126277D-09,  1.5033066103898380141D-10,MDHNKL00
     $             8.0822936042464403157D-12,  3.9473961437101054471D-13,MDHNKL00
     $             1.7590891906016512675D-14,  7.1814214762263778920D-16,MDHNKL00
     $             2.6957287823672589641D-17,  9.3358572549515461865D-19,MDHNKL00
     $             2.9922619406895981315D-20,  8.9015675760511620701D-22,MDHNKL00
     $             2.4644428505125033375D-23,  6.3656020935361057409D-25/MDHNKL00
      DATA D    /  6.7829872514427588456D-01,  4.5219915009618392131D+01,MDHNKL00
     $             3.7683262508015326776D+02,  1.1962940478735024344D+03,MDHNKL00
     $             1.9938234131225040548D+03,  2.0449470903820554375D+03,MDHNKL00
     $             1.4201021460986496090D+03,  7.1183064967350857463D+02,MDHNKL00
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     $              2.6963282184602597492D+02,  7.9891206472896585111D+01,MDHNKL00
     $              1.9021715826808013929 4D+01,  3.7188105233392256682D+00,MDHNKL00
     $              6.0764877832340288572D-01,  8.4220204895828535644D-02,MDHNKL00
     $              1.0026214868551016149D-02,  1.0363012784032058021D-03,MDHNKL00
     $              9.3867869420580235442D-05,  7.5124345274574017960D-06,MDHNKL00
     $              5.3507368429183773360D-07,  3.4135482251472901636D-08,MDHNKL00
     $              1.9618093247972931935D-09,  1.0209780508963274472D-10,MDHNKL00
     $              4.8341763773500352579D-12,  2.0913590211334783723D-13,MDHNKL00
     $              8.2990437346566602039D-15,  3.0316141496462685641D-16,MDHNKL00
     $              1.0228117913786331176D-17,  3.1967863459247792364D-19,MDHNKL00
     $              9.2821903191776400453D-21,  2.5103962999804300309D-22/MDHNKL00
      DATA CAP /    1.0416666666666666663D-01,  8.3550347222222222116D-02,MDHNKL00
     $              1.2822657455632716019D-01,  2.9184902646414046315D-01,MDHNKL00
     $              8.8162726744375764874D-01,  3.3214082818627675264D+00,MDHNKL00
     $              1.4995762986862554546D+01,  7.8923013011586517530D+01,MDHNKL00
     $              4.7445153886826431887D+02,  3.2074900908906619004D+03,MDHNKL00
     $              2.4086549640874004605D+04,  1.9892311916950979121D+05,MDHNKL00
     $              1.7919020077753438063D+06,  1.7484377180034121023D+07,MDHNKL00
     $              1.8370737967633072978D+08,  2.0679040329451551508D+09,MDHNKL00
     $              2.4827519375935888472D+10,  3.1669454981734887315D+11,MDHNKL00
     $              4.2771126865134715582D+12,  6.0971132411392560749D+13,MDHNKL00
     $              9.1486942234356396792D+14,  1.4413525170009350101D+16,MDHNKL00
     $              2.3788844395175757942D+17,  4.1046081600946921885D+18,MDHNKL00
     $              7.3900049415704853993D+19,  1.3859220004603943141D+21,MDHNKL00
     $              2.7030825930275761623D+22,  5.4747478619645573335D+23,MDHNKL00
     $              1.1498937014386333524D+25,  2.5014180692753603969D+26/MDHNKL00
C                                                                       MDHNKL00
      DATA I/(0.D0,1.D0)/,MI/(0.D0,-1.D0)/                              MDHNKL00
      DATA ONE/(1.D0,0.D0)/,TWO/(2.D0,0.D0)/,ZERO/(0.D0,0.D0)/          MDHNKL00
      DATA ROOT3/(1.7320508075688800,0.D0)/                             MDHNKL00
      DATA ALPHA/(8.53667218838951D-1,0.D0)/                            MDHNKL00
      DATA CONST1/( 2.588190451025220-01,-9.659258262890670-01)/        MDHNKL00
      DATA CONST2/( 2.58819045102522D-01, 9.65925826289067D-01)/        MDHNKL00
      DATA CONST3/(-9.65925826289067D-01, 2.58819045102522D-01)/        MDHNKL00
      DATA CONST4/(-9.65925826289067D-01,-2.58819045102522D-01)/        MDHNKL00
C                                                                       MDHNKL00
      ZPOWER=ONE                                                        MDHNKL00
      SUM3=ZERO                                                         MDHNKL00
      SUM4=ZERO                                                         MDHNKL00
      ZMAG=CDABS(Z)                                                     MDHNKL00
      IF(ZMAG .GT. 6.1D0) GO TO 70                                      MDHNKL00
      SUM1=ZERO                                                         MDHNKL00
      SUM2=ZERO                                                         MDHNKL00
      ZTERM=-Z**3/(200.D0,0.D0)                                         MDHNKL00
      DO 50 M=1,30                                                      MDHNKL00
      SUM1=SUM1+DCMPLX(A(M),0.D0)*ZPOWER                                MDHNKL00
      SUM2=SUM2+DCMPLX(B(M),0.D0)*ZPOWER                                MDHNKL00
      SUM3=SUM3+DCMPLX(C(M),0.D0)*ZPOWER                                MDHNKL00
      TERM4=DCMPLX(D(M),0.D0)*ZPOWER                                    MDHNKL00
      SUM4=SUM4+TERM4                                                   MDHNKL00
      IF(DABS(PART1(1)/PART2(1)) .LE. 1.D-17 .AND.                      MDHNKL00
     $   DABS(PART1(2)/PART2(2)) .LE. 1.D-17) GO TO 60                  MDHNKL00
      ZPOWER=ZPOWER*ZTERM                                               MDHNKL00
   50 CONTINUE                                                          MDHNKL00
   60 GM2F=I*(Z*SUM2-TWO*SUM1)/ROOT3                                    MDHNKL00
      GPMFP=I*(SUM4+TWO*Z*Z*SUM3)/ROOT3                                 MDHNKL00
      H1=Z*SUM2+GM2F                                                    MDHNKL00
```

```
      H2=H1-TWO*GM2F                                                    MDHNKL00
      H1PRME=SUM4+GPMFP                                                 MDHNKL00
      H2PRME=H1PRME-TWO*GPMFP                                           MDHNKL00
      GO TO 999                                                         MDHNKL00
C                                                                       MDHNKL00
   70 MPOWER=ONE                                                        MDHNKL00
      SUM1=ONE                                                          MDHNKL00
      SUM2=ONE                                                          MDHNKL00
      RTZ=CDSQRT(Z)                                                     MDHNKL00
      SQRTZB=RTZ*Z                                                      MDHNKL00
      ZTERM=I/SQRTZB                                                    MDHNKL00
      MTERM=-ZTERM                                                      MDHNKL00
      DM=ZERO                                                           MDHNKL00
      TERM3=ONE                                                         MDHNKL00
      DO 80 M=1,30                                                      MDHNKL00
      ZPOWER=ZPOWER*ZTERM                                               MDHNKL00
      MPOWER=MPOWER*MTERM                                               MDHNKL00
      DM=DM+ONE                                                         MDHNKL00
      TERM1=DCMPLX(CAP(M),0.D0)*ZPOWER                                  MDHNKL00
      TERM2=DCMPLX(CAP(M),0.D0)*MPOWER                                  MDHNKL00
      IF(CDABS(TERM2/TERM3) .GE. 1.D0) GO TO 81                         MDHNKL00
      SUM1=SUM1+TERM1                                                   MDHNKL00
      SUM2=SUM2+TERM2                                                   MDHNKL00
      SUM3=SUM3+DM*TERM1                                                MDHNKL00
      TERM4=DM*TERM2                                                    MDHNKL00
      SUM4=SUM4+TERM4                                                   MDHNKL00
      IF(DABS(PART1(1)/PART2(1)) .LE. 1.D-17 .AND.                      MDHNKL00
     $   DABS(PART1(2)/PART2(2)) .LE. 1.D-17) GO TO 81                  MDHNKL00
      TERM3=TERM2                                                       MDHNKL00
   80 CONTINUE                                                          MDHNKL00
   81 ZTERM=(-1.5D0,0.D0)/Z                                             MDHNKL00
      SUM3=SUM3*ZTERM                                                   MDHNKL00
      SUM4=SUM4*ZTERM                                                   MDHNKL00
      TERM1=((-0.25D0,0.D0)-I*SQRTZB)/Z                                 MDHNKL00
      TERM2=((-0.25D0,0.D0)+I*SQRTZB)/Z                                 MDHNKL00
      EXP1=CDEXP((0.D0,0.66666666666666667D0)*SQRTZB)                   MDHNKL00
      EXP2=CONST1*EXP1                                                  MDHNKL00
      EXP3=CONST2/EXP1                                                  MDHNKL00
      EXP4=CONST3*EXP1                                                  MDHNKL00
      EXP5=CONST4/EXP1                                                  MDHNKL00
      ZTERM=ALPHA/CDSQRT(RTZ)                                           MDHNKL00
      TERM4=Z                                                           MDHNKL00
      IF(PART1(1) .GE. 0.D0 .OR. PART1(2) .GE. 0.D0) GO TO 90           MDHNKL00
      H1=ZTERM*(EXP2*SUM2+EXP5*SUM1)                                    MDHNKL00
      H1PRME=ZTERM*(EXP2*(SUM2*TERM2+SUM4)+EXP5*(SUM1*TERM1+SUM3))      MDHNKL00
      GO TO 110                                                         MDHNKL00
   90 H1=ZTERM*EXP2*SUM2                                                MDHNKL00
      H1PRME=ZTERM*EXP2*(SUM2*TERM2+SUM4)                               MDHNKL00
  110 IF(PART1(1) .GE. 0.D0 .OR. PART1(2) .LT. 0.D0) GO TO 120          MDHNKL00
      H2=ZTERM*(EXP3*SUM1+EXP4*SUM2)                                    MDHNKL00
      H2PRME=ZTERM*(EXP3*(SUM1*TERM1+SUM3)+EXP4*(SUM2*TERM2+SUM4))      MDHNKL00
      GO TO 999                                                         MDHNKL00
  120 H2=ZTERM*EXP3*SUM1                                                MDHNKL00
      H2PRME=ZTERM*EXP3*(SUM1*TERM1+SUM3)                               MDHNKL00
C                                                                       MDHNKL00
C     CALCULATE WRONSKIAN AS PARTIAL CHECK ON VALIDITY                  MDHNKL00
  999 SUM4=H1*H2PRME-H1PRME*H2                                          MDHNKL00
```

```
      IF(DABS(PART2(1)) .LE. 1.D-8 .AND.                             MDHNKL00
     $   DABS(PART2(2)+1.457495441040461D0) .LE. 1.D-8) GO TO 1000   MDHNKL00
      PRINT 1001,SUM4,THETA,IDBG                                     MDHNKL00
 1000 RETURN                                                         MDHNKL00
 1001 FORMAT(' ***** POSSIBLE ERROR IN MDHNKL:  W = ',1P2E15.6,      MDHNKL00
     $       ' FOR THETA = ',0P2F10.4,' AT ',A4)                     MDHNKL00
      END                                                            MDHNKL00
```

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